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C^3 SYSTEMS ENGINEERING: A PRIMER

by

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The components of a command, control and communication (C3) system have evolved from highly sophisticated forms of electronic hardware and software innovations. Modern C3 systems such as the Joint Tactical Information Data System (JTIDS) or Airborne Warning And Control System (AWACS) incorporate a wide assortment of computers, CRT displays, communications equipment and data processing systems. These systems are developed and integrated through the means of highly proficient system engineering processes. This thesis addresses the elements of basic creative and design processes that contribute to system engineering methodology. This thesis discusses the various stages of the system engineering process which serve to integrate the design and development of such large scale systems. A case study, "CINCCENT Ground Mobile Command Post," is presented as an example of the system engineering process.

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C3 System Engineering: A Primer

by

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ABSTRACT

The components of a command, control and communications (C3) system have evolved from highly sophisticated forms of electronic hardware and software innovations. Modern C3 systems such as the Joint Tactical Information Data System (JTIDS) or Airborne Warning And Control System (AWACS), incorporate a wide assortment of computers, CRT displays, communications equipment and data processing systems. These systems are developed and integrated through the means of highly proficient system engineering processes. This thesis addresses the elements of basic creative and design processes that contribute to systems engineering methodology. This thesis discusses the various stages of the system engineering process which serve to integrate the design and development of such large scale systems. A case study, "CINCCENT Ground Mobile Command Post," is presented as an example of the system engineering process.

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I. INTRODUCTION

A. BACKGROUND

The growth of technological innovation has led to many remarkable advances in a variety of fields, such as medicine, aerospace, communications, transportation and weapon systems. Innovation is the product of a continuous process which pits the intellect of the designer against a host of problematic situations. The conversion of these problems into practical systems is a form of problem solving that has been perfected over centuries of practice.

Specifically in the field of command, control and communications (C3), the rapid technological changes which continuously occur create newer and better communications, data processing, and sensing equipment each year. Technological advances in such areas as microelectronics, computer graphics and superconductivity are being made at an unprecedented rate. These new technologies are constantly being reapplied toward the design of more sophisticated C3 systems on a variety of different scales.

Large scale C3 systems that are in place must now be capable of accepting new features in an evolutionary way (open systems architecture) in order to react to changing needs, modernization, or new technological capabilities. What is needed is a system engineering approach to C3 systems architectures that is both sensitive to the growing technological trends in industry and flexible enough to adapt these innovations to the changing needs of the warfare commander. In the author's

experience, all too often in the interest of time and budget constraints, or lack of experience, crucial steps in the design and development phases of a system engineering program are omitted, and as a result, important capabilities are not realized. It is imperative that C3 system developers be thoroughly grounded in the principles of system engineering.

B. PURPOSE

The goal of this thesis, then, is to provide the reader with a basic understanding of the various concepts and principles relating to system engineering as they pertain to the development of a command and control system. It covers the elements of basic creative and design skills; the different stages of the system engineering process; and presents as a case study, the definition of a CINCCENT mobile command post, a term project developed for course CC4003, C3 System Engineering, at the Naval Postgraduate School.

C. SCOPE

This thesis is organized into three main chapters. The first chapter of this thesis explains both the creative and design processes. Designers are often too overwhelmed with design requirements to pick a suitable starting point for their creative analysis. Guidelines and examples are provided of several procedures which can be utilized to allow designers to most effectively apply their creativity. Additionally, a detailed look at the design process is presented offering the reader an overview of various approaches to this seemingly complicated process. The second chapter discusses the system engineering process and its importance. The

phases that comprise this process are analyzed and explained so that the reader can gain a productive insight into system engineering. The last chapter of this thesis will attempt to draw together the concepts that were previously presented and illustrate their application by using a term project entitled, "CINCCENT Ground Mobile Command Post," as a case study in the engineering of command and control systems. Finally, in the appendix, the key system performance and design requirements are summarized in the form of a Top Level Specification.

II. ELEMENTS OF THE CREATIVE AND DESIGN PROCESS

> Imagination is more important than knowledge, for knowledge is limited, whereas imagination embraces the entire world--stimulating progress, giving birth to evolution. Albert Einstein

> Design is regarded as the process of selectively applying the total spectrum of science and technology to the attainment of an end result which serves a valuable purpose. R. J. McCrory

The purpose of this chapter is to assist in developing a capacity for design. Design will be described as a number of fundamental principles and relationships known as the design and creative methods. An individual should acquire all the necessary tools of the profession and gain confidence and proficiency in their application. A designer must realize that these processes serve only to structure his thinking along a guided and hopefully productive path. They will not produce, in themselves, the end-all solution to any design query. The designer must combine these tools with imagination and reason. As Harold Buhl states in his book, Creative Engineering Design:

> Without reason he would have mere fantasy and without imagination he would never begin. Without imagination an idea is cold and conservative, without call for great achievement. [Ref. 1:p. 11]

A. TRADITIONAL AND MODERN AREAS OF DESIGNING

Throughout history there have been countless examples of how man has altered his natural environment to produce a desired effect. The Egyptians built extensive canals during the rainy seasons to take advantage of the Nile's flood waters. King Herod built an elaborate pier, breakwater and lighthouse in the port city of

Caesarea in 22 B.C. capitalizing on the Roman Empires expansive trade routes throughout the Holy Land. Not all ancient undertakings were this elaborate. Some were simple marvels such as watermills, an ingenious way to harness the power of a river to drive saws, grinding stones and drills. Others involved the application of labor practices handed down from generation to generation in spoken tradition.

The earliest initiators of change in the natural world were skilled craftsmen, "designers who take over where natural evolution leaves off." [Ref. 2:p. 15] A cartwright, for example, typically designed and constructed wagons in the same manner as his father; his father in the same manner as his grandfather and so on. Whether it was a four masted schooner, a magnificent palace or a farm wagon, the essence of these developments came from the analytical processes inside the mind of a designer, who preserved for generations a seldom changing procedure involving materials, structure and form. In his book, Engineersmanship: A Philosophy of Design, Lee Harrisberger writes:

> Technological progress has been totally dependent upon the evolution of power, materials, and tools. Each has been dependent on the others. The need for improvement of a particular machine usually hinged upon the availability of a better material. Likewise, the availability of a new material required better machine tools to manufacture this material. The development of better tools and better material made it possible to create machines with a greater capacity to do work and, of course, increase the necessity for more power to drive these machines. [Ref. 3:p. 9]

Changing the natural world to reflect a growing technical, industrial or social need was the impetus for the craftsman and his trade. Modern society is overwhelmed with technological advances. Today, the process of bringing about change in man-made things is paramount to the designer. Incorporating these new technologies or inventing new ones requires the designer to use current information

to make predictions about a future state that will not come about unless their predictions are correct. [Ref. 4:p. 9] What has evolved since the times of King Herod and the colonial craftsmen is a science of design, where an individual who understands specific design attributes and procedures can follow sequential steps and ultimately produce a product worthy of public acclaim.

B. DEFINITION OF DESIGN

There are many definitions of design which are used to describe this activity. One of the more salient definitions appears below.

> Engineering design is the use of scientific principles, technical information and imagination in the definition of a mechanical structure, machine or system to perform prespecified functions with the maximum economy and efficiency. [Ref. 5:p. 4]

There is one idea that is central to the traditional and modern areas of design--the initiation of change. We saw that designers in ancient civilizations, Renaissance and Colonial craftsmen, and modern designers were the innovators. Their ideas brought forth change effecting all aspects of society. They all followed a similar unspoken step by step procedure which allowed them to analyze the natural or built environment, and through their ingenuity brought about change.

In the late fifties and early sixties, academic attention was focused on design and many insightful works were published. Men such as Christopher Alexander, J. Christopher Jones and Morris Asimov all contributed vast amounts of time and research into the development of design and creative methods. Their work disproved a growing belief that design was an activity that only gifted individuals could perform. Each of these design theorists analyzed the separate elements which

contribute to the practice of designing, and constructed a process that could be followed and understood by everyone.

C. THE DESIGNER'S OBJECTIVES

The removal of an inhibition, or reluctance, on the part of a novice designer to assume responsibility for his work is an essential characteristic, that can be learned by training in design principles. Understanding that there is no single answer or solution to a design problem, and that often hard decisions must be made among a host of alternative solutions is the greatest dilemma the designer must be prepared to face. The way to resolve this inevitable dilemma is to gain knowledge, ability and experience in the principles of design so that wise choices can be made during the design phase, and there will therefore be less potential for negative impacts during the development phases of the project.

D. THE CREATIVE PROCESS

Creativity in the development of new ideas has been a quality that private industry and the military have sought after for over a quarter of a century. People capable of creative thought will always be in demand especially in this era of shrinking budgets, environmental constraints and competition for marketing and material resources. Lee Harrisberger, author of Engineersmanship: A Philosophy of Design, writes:

> The creative ability of man could easily be regarded as our greatest natural resource and, no doubt, our greatest undeveloped natural resource. It is human quality that makes the impossible real, anticipates the future and extrapolates reality. It is the principle source of our progress, man's most distinguishing ability--a noble attribute of the human mind. [Ref. 6:p. 34]

Not long ago, it was common practice to believe that people were born with creative minds. The ability to resolve complex problems quickly and correctly was believed to happen naturally for some. It was considered that you were either born with creative talent or you were not. More recently, behavioral scientists have compiled a wealth of information on individual creativity, notably:

- We have developed techniques for measuring relative creative ability.
- We have discovered that creativity is not an inherited uniqueness. We all have the ability in various degrees--and it can be cultivated.
- We have developed some useful techniques for teaching people how to become more creative.
- We have investigated the relationship of intelligence to creativity and have discovered a disturbing paradox--they do not relate. [Ref. 7:p. 37]

Just as a person can be trained to sing and improve on an already confirmed ability, another individual can be taught to be more creative. It involves a simple process of overriding the psychological factors which inhibit creative thought: "As long as you believe you can't, you won't." [Ref. 8:p. 39] Researchers have found that most people follow a series of mental steps when confronted with a problem that requires creative ingenuity. There is no information as to why these steps have evolved this way, but they are widely experienced.

For comparative analysis, two author's opinions on the creative process will be examined. First, Lee Harrisberger has outlined four steps in his creative process:

- Preparation - Defining the situation.
- Search - Seeking ideas, mulling the facts.

- Frustration and illumination - Ideation, mental struggle.
- Evaluation and execution - Choosing the way and communicating. [Ref. 9:p. 41]

These steps describe a variety of emotional actions and reactions which an individual undergoes when solving creative obstacles. He amasses as much information about the problem at hand, never letting subjective opinions or hearsay effect his judgment. Next, the problem is posed as a series of interrelationships and a cause-and-effect study is compiled. Ideas start to form. The process continues as the individual continues this mental struggle and constantly changes from one idea back to another, refining old thoughts to produce new ones. Suddenly, the light goes on, "bingo!" there is intense elation, and the idea is carefully explored. Ultimately, it is explained or demonstrated, and the problem is resolved.

A second definition of the creative process was posed by Percy Hill in his book, The Science of Engineering Design takes a similar approach:

- Irritation and decision - Necessity is the mother of invention.
- Preparation - Direct mental effort.
- Incubation - Letting the subconscious mind go to work.
- Illumination - The creative answer appears in a flash.
- Verification - Judging or proving the ideas validity.[Ref. 10:p. 25]

Hill argues that creativity is triggered by an annoying situation. Such a situation, in turn, defines the problem, and a need arises to solve it. The preparation involved here applies directly to, again, a series of relational studies and

various combinations which could lead to a satisfactory answer. With all the variations considered and reconsidered, the mind must be allowed time to subconsciously explore these proposed solutions or invent some more. When the designer is doing something completely foreign, totally unrelated to the problem, and the solution flashes in front of him, illumination has occurred and now the idea waits to be judged.

These two procedures are very similar with the exception of a few points. Where Harrisberger implements the beginnings of his creative approach with the recognition of a problem, Hill contends that it is irritation that leads to the identification of the problem. In either step, despite their dissimilarities, they both involve a statement or analysis of the problem. The authors agree that there is a preparation phase, but the context of these two steps are different. Harrisberger views preparation as gathering specifics about the problem, i.e., problem definition. The final steps all seem to compliment each other. Hill sees preparation as solution generation and the manipulation of ideas. They both recognize the need for a mental struggle, an attempt to put ideas and pieces together; illumination, the sudden realization that the problem can be solved; and finally, evaluation or verification of the solution.

E. AIDS TO THE CREATIVE PROCESS

The creative process is a simple template for the designer to follow when confronted with a design problem. The designer proceeds through the stages at his own pace, identifying requirements, inventing solutions, modifying ideas and

eventually solving the problem. At his disposal are certain tricks-of-the-trade which can be applied in a number of ways. These aids are: brainstorming, functional visualization, an idea matrix and an idea diagram. They should be applied during Lee Harrisberger's search phase or Percy Hill's preparation phase.

1. Brainstorming

Many designers are afraid to work with others for fear of being criticized. If an idea, for example, is expressed and met with strong unconstructive disapproval, the originator may not wish to try out or continue to express unproven thoughts. The implications this has at the start of a design project are obviously disastrous. It is usually "far-fetched" ideas that become the building blocks for more creative and applicable ones.

Brainstorming was developed to remove any criticism or fear of criticism during group idea sessions. Everyone is expected to contribute freely to the conversation and operate in a calm and relaxed fashion. A group of five to ten people tend to work the best together provided that the session does not take longer than 45 to 60 minutes. There should be a chairman, one who moderates the conversation and brings with him some ideas which inspire initial thought. A recorder should also be available to record every idea for later reference.

Percy Hill suggests the following rules for profitable sessions:

- Criticism of ideas is not permitted,
- "Free-wheeling" or "loose-thinking" is welcome,
- Ideas are wanted in quantity,

- Transpose thoughts and combine ideas. [Ref. 11:p. 23]

The first rule should be strongly enforced. Anyone violating it should be cautioned or asked to leave. "Criticism often leads to ridicule which stifles creative thinking." [Ref. 12:p. 23] The second rule encourages unconventional thoughts. Wild ideas are wanted, and final judgment on these ideas are decided later. Alex Osborne states, "The wilder the idea, the better; it's easier to tame down than to think up." [Ref. 13:p. 23] The third rule stresses quantity, not quality. The object is to generate lots of ideas. Since there is no criticism allowed in brainstorming, one idea is as good as the next. And finally, the fourth rule allows group members to improve on the ideas of others. By combining certain ideas, alternative possibilities are constructed and idea quantity increases.

2. Functional Visualization

The primary purpose of this concept is to define the problem at hand in terms of its functional attributes. What exactly needs to be done? For example, a designer might be asked to invent a unique or novel lawn mower. He may invariably picture the conventional rotary blade mower and adapt some improvements. Using the functional visualization technique, the designer might ask instead, design a method for shortening grass. [Ref. 14:p. 20] In short, functional visualization attempts to unite the function to be performed with the methods of achieving that function.

3. Idea Diagram

Whereas the mind can process one thought at a time, the eye can readily scan an assortment of information and simultaneously distinguish one form from another. The idea diagram is a useful tool in idea development because it can clearly display all possibilities, and it "adds a dimension of flexibility to the mind in seeking alternatives to a problem or task." [Ref. 15:p. 21]

Figure 1 is an example of how an idea diagram is used. Here, the designer is exploring ideas for a transportation system. The diagram begins with a list of headings and it is then decomposed into subheadings and sub-subheadings. Percy Hill applauds the use of idea diagrams. In his book, Science of Engineering Design he writes:

> It is good practice to sketch some of the ideas for a clearer understanding since it forces the designer to offer positive evidence of his thinking. [Ref. 16:p. 21]

4. Idea Matrix

The idea matrix, or morphological chart, entails analyzing the problem in considerable detail to determine the key independent variables that are specific to the problem. Each of these variables are then arranged independently and examined for possible choices for driving alternative solutions. These parameters are subdivided and entered separately to form a matrix grid. The matrix allows all information to be cross correlated to produce hundreds of idea solutions to the problem.

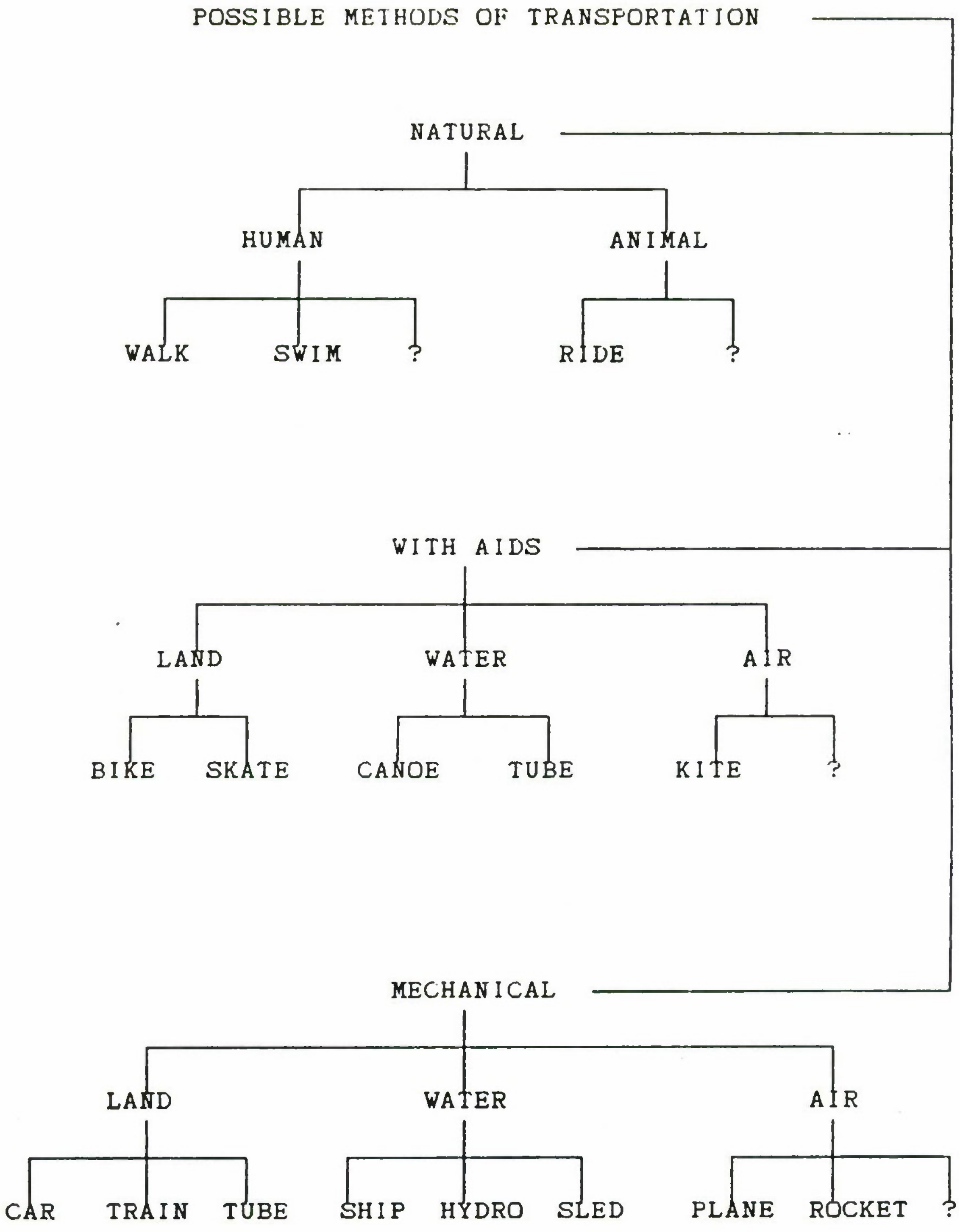


Figure 1.
(From Ref. 10)
Typical Idea Diagram

Figure 2 is an example of a morphological procedure which illustrates a chart of sample solutions for a manually propelled propulsion system for a small boat. The left hand column reflects the possible choices which can be explored to develop the mechanical linkages and characteristics of the design. The subsequent rows list alternative ideas which are related to the chosen parameter heading that row. [Ref. 17:p. 60]

For example, what are the types of input devices which can be considered to propel a boat? The chart shows that there are cranks, turnstiles, pedals, levers and treadmills. Similarly, other attributes are assigned to the parameters on the left. The result is a comprehensive study of the many alternative methods which can be explored to propel this small boat.

These four methods are just a sampling of some of the many means available suited for idea generation. For more information, students are encouraged to consult Lee Harrisberger's book, Engineersmanship: A Philosophy of Design. [Ref. 3]

F. THE DESIGN PROCESS

The design process allows designers to understand their own behavior, and ultimately, improve their design ability. It is a specialized process of problem solving which involves, as Morris Asimov sees it, a variety of steps:

> The design process describes gathering, handling, and creative organizing of information relevant to the problem situation; it prescribes the derivation of decisions which are optimized, communicated, and tested or otherwise evaluated; it has an iterative character for often, in the doing, new information becomes available or new insights are gained which require the repetition of earlier operations. [Ref. 18:p. 44]

PARAMETERS Design Characteristics	IDEAS Design Alternatives				
Input Motion	Rotating	Oscillating	Linear	Piston	
Input Source	1 Hand	2 Hand	2 Foot	Hand and Feet	
Input Device	Crank	Pedals	Lever	Treadmill	Pully
Output	Propeller	Paddle	Fin	Screw	Jet
Mechanism	Gears	Chains	Belts	Pump	Linkage
Operator Position	Sitting	Standing	Kneeling	Straddling	

Figure 2.

(From Ref. 3)
Morphological Ideation Chart:
A Manual Propulsion System For A Small Boat

For the novice, design appears to be a combination of the behavioral and representational parts of the design process, such as gathering information, studying the problem, or developing drawings. What exactly occurs inside the mind of the designer? Several respected design theorists: John Zeisel, Percy Hill and Morris Asimov have gathered evidence to suggest that designing is a combination of personal experiences, participant observation, reports by designers, and analysis of designs. These design theorists have developed different analogies of how the various processes fit together. [Ref. 19:p. 5]

In his book, Inquiry by Design, John Zeisel views the design process as an ordered procedure which requires intense analysis and determination to want to reach a desired goal. He states:

> Design can also be seen as an ordered process in which specific activities are loosely organized to make decisions about changing the physical world to achieve identifiable goals. [Ref. 20:p. 5]

Zeisel proposes that there are five characteristics to the design process which nicely summarize what designers do:

- Three Elementary Activities - Imaging, presenting, and testing.
- Two Types of Information - A heuristic catalyst for imaging and as a body of knowledge for testing.
- Shifting Visions of Final Product - To continually modify predictions about a final result in response to new information and insight.
- Toward a Domain of Acceptable Responsibilities - Designers aim to reach one acceptable response within a range of possible solutions by measuring how well a product is adapted to its environment and how coherent constituent parts of the product are with one another.

- Development Through Linked Cycles: A Spiral Metaphor - Product development in design occurs as the result of repeated, iterative movement through the three elementary design activities.[Ref. 21:p. 6]

Zeisel strongly believes that in order to organize and operate in the context of a design behavior and to achieve a desired objective, designers must learn to see the process as a loose ordering of the three main activities outlined in his first characteristic of design: imaging, presenting and testing.

Imaging is to the designer as a canvas is to a painter. It allows the mind to form a mental picture of something which has never been seen or described before. Imaging provides designers, "...with a larger framework within which to fit specific pieces of a problem they are to resolve." [Ref. 22:p. 7]

Presenting involves a complex, yet expressive, series of sketches, plans, models and photographs which are useful to communicate a designers images and ideas. It is a tool that the designer and prospective clients can use to understand one another, elaborate important concepts, and "flush-out" important characteristics which might not have been previously considered.

Testing is the final component of the three elementary activities and describes the presented information against an array of information, such as: the designer's and client's implicit images, explicit information about constraints and objectives, degrees of internal design consistency and performance criteria--economic, technical and sociological. [Ref. 23:p. 9]

Zeisel's design process continues with a look at the two types of information designers have available. Image and test information are considered separate

entities, each supporting a belief that different forms of information are useful to designers and can promote creativity and innovation:

> Image information provides a general understanding of important issues and of physical ideas pertinent to their resolution. Test information is directly pertinent to evaluating the good and the bad points of a given hypothesis design. [Ref. 24:p. 10]

Image information conveys a feeling or a mood of some environment, for example: What is the meaning of school in a child's life? or, What is life like for someone confined to a wheelchair? Test information is used to evaluate specific design alternatives; for instance: is it more natural for people to turn faucet handles on by using a clockwise or counter-clockwise rotation?

The third characteristic of design, shifting visions of final product, is an iterative process which allows a designer through constant revisions and evaluation, to eventually refine their ideas. This helps to:

> ...test the presentation of a tentative design response against quality criteria within the situation and its context to find out where the response is strong and where it is weak. [Ref. 25:p. 11]

Testing helps designers to "re-image" their designs with greater sensitivity towards the attributes which originally shaped their images of the future product they intended to design.

Zeisel's fourth characteristic, toward a domain of acceptable responses, explains how designers decide what is acceptable. For example, how do they decide on a final design to be built? We know that among an infinite number of possible solutions exist a finite number of suitable ones. Moreover, for some complex problems, there may be no solution at all. Typically designers make decisions about practical, substantive attributes of the objects being designed.

Material properties, such as weight, strength, and size; environmental properties, such as light, climate, or; administration properties, like cost or marketability all contribute to the processes which lead a designer to a final decision.

And finally, Zeisel's fifth characteristic uses a spiral metaphor to describe the constant appraisal and reappraisal of the design elements and how they fit together. There are three trends which depict this fifth characteristic:

- Designers seem to backtrack at certain times -- to move away from, rather than toward, the goal of increasing problem resolution.
- Designers repeat a series of activities again and again, resolving new problems with each design repetition.
- These apparently multidirectional movements together result in one movement directed toward a single action.[Ref. 26:p. 14]

Figure 3 shows the design development spiral metaphor beginning with the initial information (image formation) and follows a path of continued refinement and testing until the process enters the domain of accepted responses, and eventually, completion.

Percy Hill's view on design offers an unambiguous approach to the sequence of events which cause a design to logically unfold. It is not to be regarded as the formula which will guarantee a product, but as a tool which will allow a designer to understand what step he is on, and where his next step shall take him. Hill sites twelve steps of his design process:

- Identification of need - The irritation of knowing something must be done to correct or resolve a situation.

- Definition of goal - The designer's commitment to designing a system, devise or process to satisfy the need.
- Research - Gathering all information relevant to the goal.
- Task specifications - An understanding of all pertinent data and parameters that will control the design toward the desired goal.
- Ideation - The formulation of new ideas.
- Conceptualization - An inventive activity in which alternative solutions are generated.
- Analysis - Testing the alternative solutions against physical laws.
- Experiment - Prototyping or laboratory testing to determine performance characteristic, reliability, durability.
- Solution description - Specific information that defines the system, process or device.
- Manufacture - Consideration of production, fabrication quality control techniques.
- Distribution - Competitive pricing, advertising, marketing and profit margin.
- Consumption - Consumer feedback, service, and repairs. [Ref. 27:p. 37]

The design of a device, or system, has a number of objectives imposed upon it, including cost, time, performance criteria, feasibility, or aesthetics. Hill contends that these objectives require designers to follow a methodology in order to ensure that something useful will result. Figure 4 illustrates the above mentioned steps in the form of a flow diagram beginning with identification of need and ending with consumption. The steps are iterative, allowing room for continual updating and evaluation. The greatest iteration loop occurs between conceptualization and analysis, where:

A general image of the design is tested against the laws of nature, reconceived and retested to bring it into a reality. [Ref. 28:p. 37]

Morris Asimov's design process carries the designer through analysis, synthesis, evaluation and decision, and extends into the realms of optimization, revision and implementation.

Analysis of the problem situation is a very crucial first step. It makes clear the goals that are to be achieved, what difficulties are to be overcome, what resources are available, how constraints drive solutions, and finally, what criterion should be used to judge the goodness of a possible solution. [Ref. 29:p. 45]

Once the problem is defined, a synthesis of solution follows. Asimov states:

A solution is a synthesis of component elements which hurdles the obstructing difficulties and, neither exceeding the available resources nor encroaching on the limits set by constraints, accomplishes the prescribed goals. [Ref. 30:p. 45]

Designers rely on their past experiences, and draw from memory a variety of combinations or "elements." "Elements" may be of ideas or of physical things that, when ordered into a proper combination, create potential answers to resolve the situation.

Evaluation and decision requires that the designer use logic and mathematics to determine which solution is an optimal one. Asimov suggests measures of performance (MOP) to assist the designer in evaluating the possible solutions.

Having the evaluations, we make the decision of which solution to adopt by taking account of the possibility that any particular solution might turn out unfavorably. [Ref. 31:p. 46]

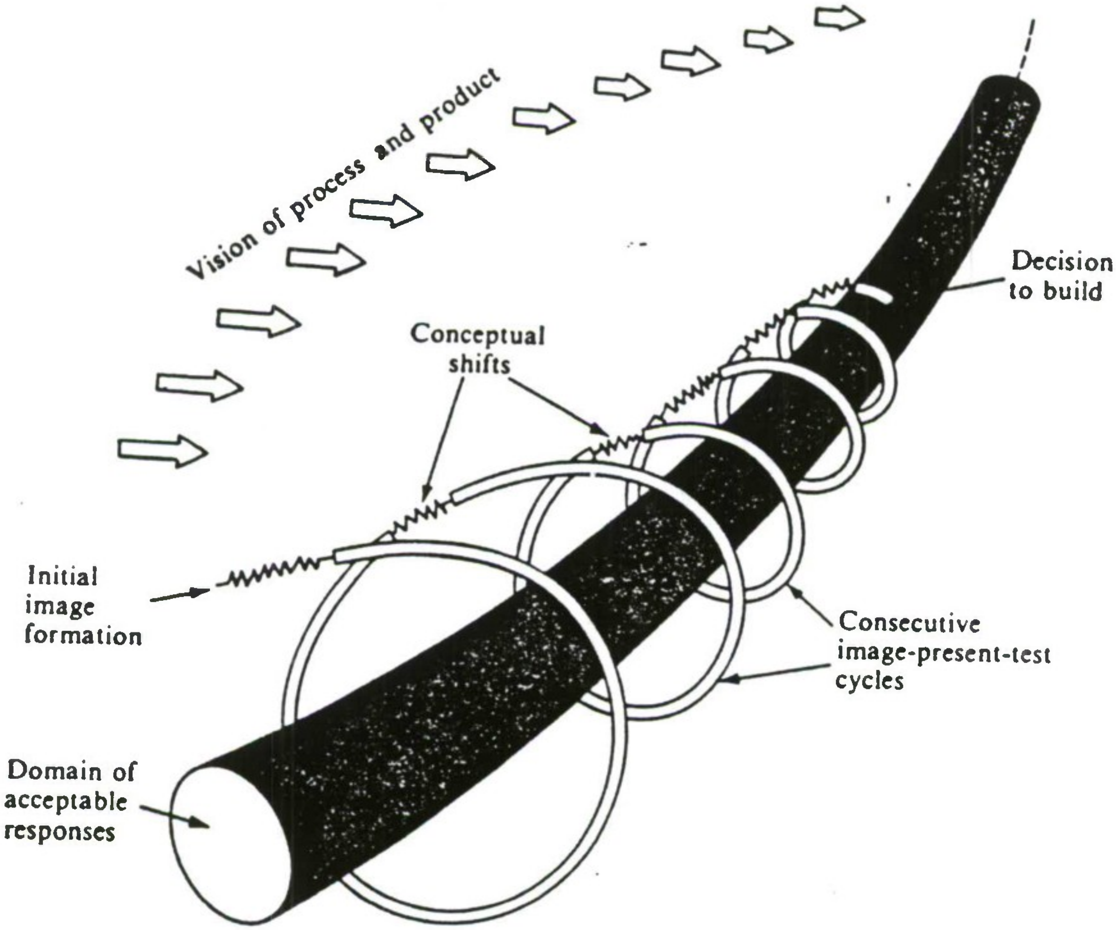


Figure 3.
(From Ref. 19)
The Design Development Spiral

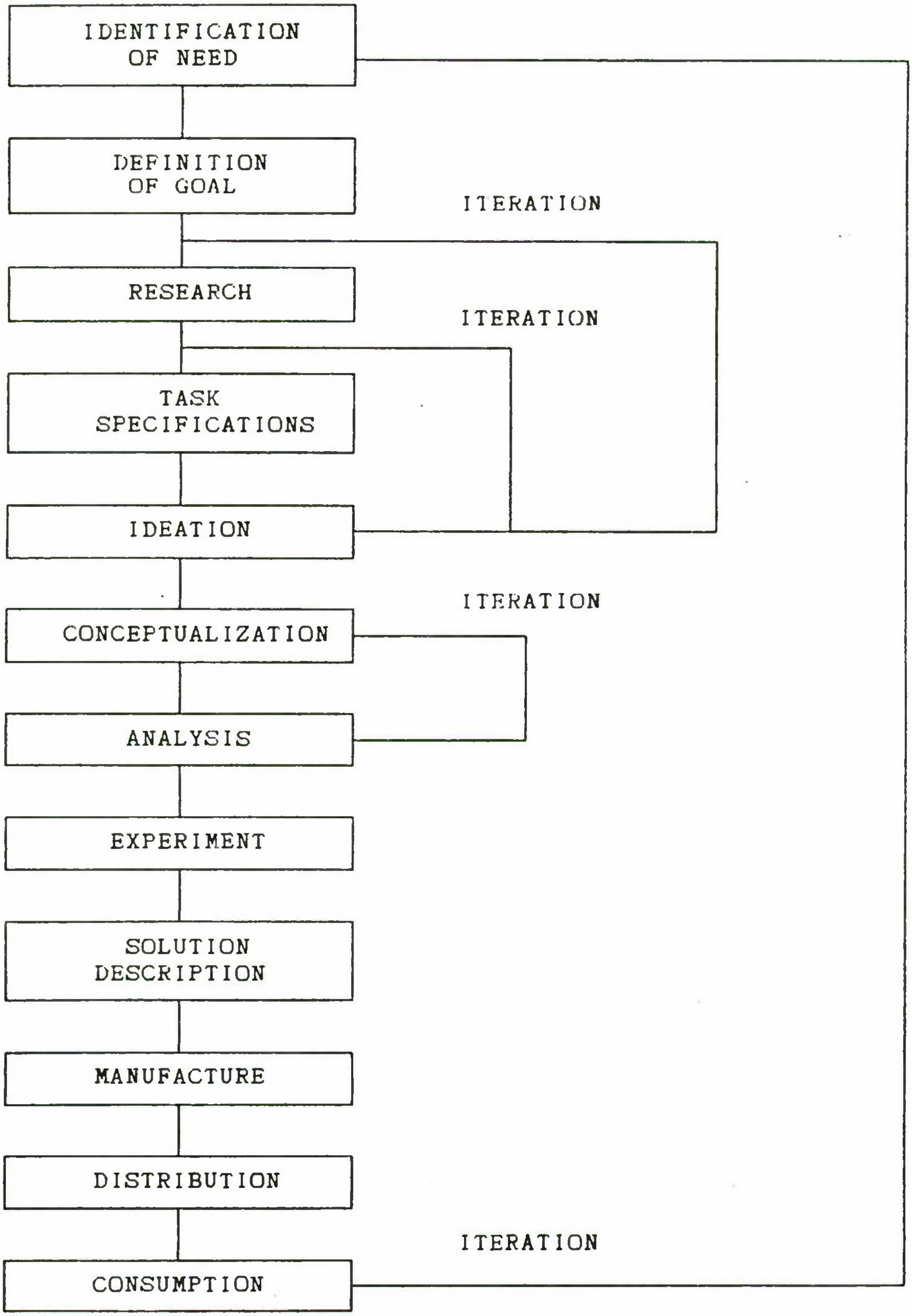


Figure 4.
The Design Process
(From Ref. 10)

Optimization involves taking the solution and refining it to a level of perfection, up to the highest level that the problem constraints allow without changing the design.

> ...design criterion has been formed which is appropriate to the particular design problem and suited to its position in the hierarchy of design objectives. The optimal set of design parameters exists only in relation to the criterion; when the latter is altered, a different set of parameters will be obtained, that is, we will have a different design. [Ref. 32:p. 84]

Asimov's revision phase of his design process comes on the heels of testing the various solutions. Testing is an common yet important step in design, "if there is any reasonable doubt about (a solution) being satisfactory." [Ref. 33:p. 46] Testing reveals flaws which may have gone unnoticed, and through revision and iteration, produces a solution which complies to the constraints and reaches the goal.

Implementation, as Asimov sees it, is dependent on communication. For a designer to communicate his solution is perhaps the biggest adventure he must endure. It is filled with a series of pitfalls and misperceptions. On one extreme there is the media who carries the solution to the public, or on another, the designer who must sell his idea to prospective buyers. Communication is the only way, however, to implement the solution.

G. SUMMARY

Methodology in design is not a formula or even a prescription that will guarantee a product. It should be considered rather as a sequence of events known as the creative and design processes within which a design can be caused to unfold logically. The creative process gives designers a framework in which to understand

how ideas can be generated. The techniques used for creativity are not limited to a privileged or gifted few, but to all who wish to properly channel their naturally occuring creative ability. The design process is a trail-and-error sequence among a number of alternatives, in which each decision is affected by compromise between a number of conditions and constraints. It demands meticulous attention to detail; the coordination of a wealth of information; the search for a variety of ideas at every stage, and; an over-all necessity to achieve the best performance at the lowest cost in the shortest possible time. [Ref. 34:p. 87] The design process can serve as a useful reference in, "defining where we are, where we ought to be, and the next step in executing a complete design." [Ref. 35:p. 37]

Chapter III will discuss the system engineering process and its associated stages. Hopefully, the reader has gained an insight into the design and creative processes that will assist in his understanding of another process that is vital in the development and management of new systems.

III. STAGES OF THE SYSTEM ENGINEERING PROCESS

> For which one of you, when he wants to build a tower, does not first sit down and calculate the cost, to see if he has enough to complete it? Otherwise, when he has laid a foundation and is not able to finish, all who observe it begin to ridicule him, saying, "This man began to build and was not able to finish." Luke

A. INTRODUCTION

For many of us, simple activities appear to be just that--simple activities. The simple routines which occupy parts of our daily lives receive little notice or attention because they are often performed in a regular fashion. Interestingly, waking up, preparing a meal, going to the bank or driving to work (simple activities) are part of a larger, more complex organization of routines. Each one of these daily activities is in fact a specialized task designed to operate within a larger order of events. These routines are mere subfunctions of different systems, such as the social, economic and political ones which govern the way we live, earn money or invent technology. It, therefore, should become evident to the reader that there are many different factors which contribute to the way in which a system performs. Whether or not it is a type of social or mechanical system is not important. What is important is that in order to develop a system, the designer must define a selective set of inputs for every desired output, or overall mission he wants the system to perform. This is precisely the point when defining what is exactly meant by a "system." Harry H. Goode, in his book System Engineering, defines it as a collection of simple

activities "which contribute to the production of a single set of optimum outputs from a given set of inputs." [Ref. 36:p. 5]

Often a graphic representation of a system is used as shown in Figure 5. A rectangular box depicts the system which takes input signals from the left and produces output signals on the right. This diagram is often referred to as a black box since there is no information describing the components or nature of their interconnections. [Ref. 37:p. 1]

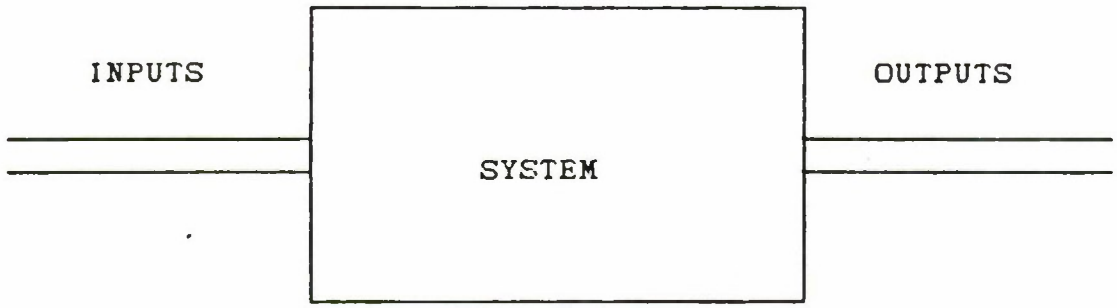


Figure 5.

A Typical Black Box Configuration
(From Ref. 37)

Roughly 500 years ago, men like Leonardo da Vinci and Filippo Bruneleschi were not only masters of the arts and sciences, but of technology and literature as well. The relatively slow rate of technological advancement allowed for numerous Renaissance thinkers to achieve distinction in all scholastic interests, not just one.

Today we are more specialized. All that there is to know can no longer be circumscribed by the genius of one man, but must be subdivided into more detailed fields of study.

For today's large scale problems, teams of specialists, engineers and scientists must pool their expertise in a joint effort to conceptually solve a problem, and ultimately, develop an operational system. These engineers and scientists who "lead a large project and organize the system effort," [Ref. 38:p. 8] are referred to as system engineers; and, the methodology by which these large scale systems are developed is called system engineering.

B. FUNDAMENTAL DEFINITIONS

In order to better understand the principles of system engineering, it is wise to establish a clear definition of the term. The term typically has many definitions and meanings which lead to differences in opinion among system engineers. Harold Chestnut, author of System Engineering Tools defines system engineering as, "a practice which involves the overall considerations of varying methods of accomplishing a desired result." [Ref. 39:p. 8] This is adequate, but does not address the specific methods that are used to accomplish a desired result. J. A. Morton's article, "Integration of Systems Engineering with Component Development," gives a more feasible definition of system engineering by explaining it as a method which:

> ...recognizes each system as an integrated whole even though composed of diverse, specialized structures and subfunctions. It further recognizes that any system has a number of objectives and that the balance between them may differ widely from system to system. The methods seek to optimize the overall system functions according to the weighted objectives and to achieve maximum capability of its parts. [Ref. 40:p. 88]

System engineering involves a process whereby certain methods are used to produce a desired outcome. Whether it is a civil or military system, there are several common precepts that each of these systems address during the system engineering approach. Harold Chestnut lists five objectives that are basic to all system engineering processes:

- The idea of change. The present is merely an integrated result of the past; it is also the foundation or springboard for the future.
- There are alternative ways of accomplishing things. What are the most suitable of the various ways in which the objectives being sought can be obtained.
- Commonly accepted bases for judging the value of a system. The major, commonly accepted standards for judging a system include: (a) reliability; (b) cost; (c) performance; (d) time; and (e) maintainability.
- Each system has its own environment and is in fact a subsystem of some broader system.
- Computational and experimental techniques. It may be cheaper and quicker to calculate or measure a model or simulation of a system or part thereof than it is to build and try out the actual system. [Ref. 41:p. 12]

C. SYSTEM ENGINEERING PROCESS

The system engineering process involves the use of logically sequenced activities which lead to the construction and operation of a system. Figure 6 is a illustration of the systems engineering process as defined by Professor Lacer in C3 System Engineering, CC4003. It shows eight phases, each logically connected with the next, but also, in practice, operate as a closed loop iterative process.[Ref. 42:p. 4] The feedback loops serve the design team in that they allow continuous analysis and updating so decisions in subsequent phases of the process can be used to

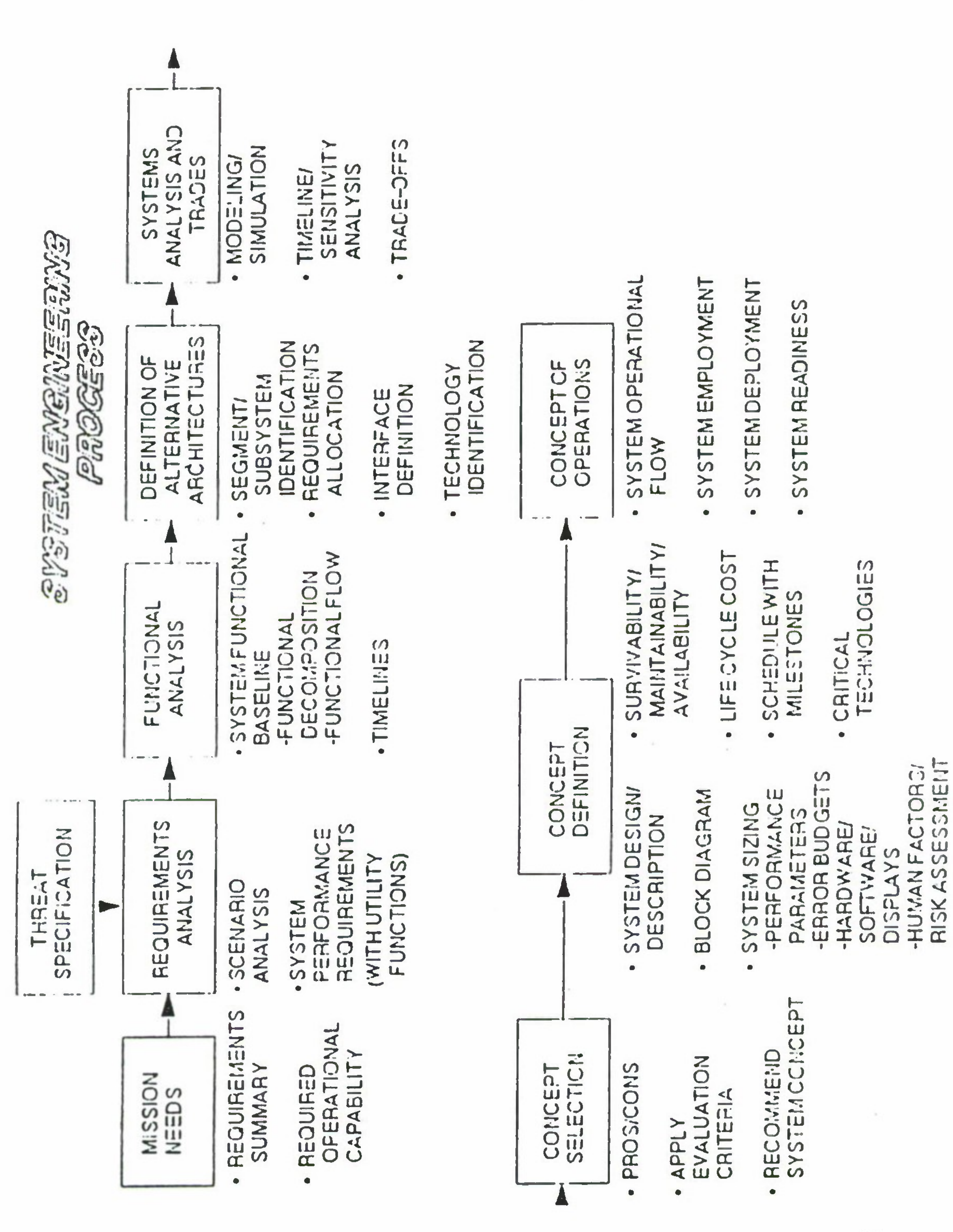


Figure 6.
(From Ref. 74)
The System Engineering Process

reoptimize overall system performance. The initial mission operational requirements which reflect the needs of the user ultimately define system performance requirements that must be designed into the system. The system performance requirements, in turn, are used to define a more precise list of functional requirements. It is through this process that mission needs are transformed into specific, more functionally oriented needs. The aims of the system engineering process are twofold:

- To establish overall system performance requirements and to ensure that the system candidate that goes forward for acquisition and operation satisfies, whole-system, whole-life, cost-effectiveness criteria with respect to the define requirements.
- To ensure that all aspects of the design, development and production during the acquisition phase are so planned, monitored and integrated that the assembled and operational system does have in fact achieved the specified performance within the cost-effectiveness boundary. [Ref. 43:p. 65]

The following list summarizes the eight phases of the system engineering process. Each phase will be defined in terms of its application and importance to the system engineering process, and in some instances, will offer an example of the way these phases can be implemented.

- Mission need,
- Requirements analysis/threat specification,
- Functional analysis,
- Definition of alternative architectures,
- System analysis and trades,
- Concept selection,

- Concept definition, and;
- Concept of operations.

The above list is a detailed collection of specific procedures rather than the objectives of Harold Chestnut given in the preceding section. The reader will note that elements from Chestnut's five objectives are contained in Professor Lacer's listing of the system engineering process. The purpose of specifying the system engineering process is to provide system engineers with a clearer and more defined method that is capable of examining every stage of the system engineering process in greater detail.

1. Mission Need

This is the formal starting point of the system engineering process. The mission need is a proposal generated by the users which formally expresses a need for the development of a new system, and specifies the desired objectives and functions the system is expected to perform. Additionally, it is the springboard for the design team to begin feasibility studies to see if the technology is available for production or to begin comparative studies to see if there is a comparable system already in place which can be modified to accomplish the users objectives.
Following this initial step, both the users and system engineers can proceed with the engineering process interacting with a common understanding about the scope and intent of the project.

2. Requirements Analysis

This is the most important phase of the system engineering process. Both the designer and user must be fully aware of the potential for system failure or success in the requirements generation phase. Poor requirements definition can lead engineers down unproductive paths and contribute to costly embarrassments. In his testimony to the House Armed Service Committee, Dr. William Perry commented on how the requirements of a system were not considered by the contractor:

> The (acquisition) system which we looked at...is flawed in fundamental ways. It's flawed at the very beginning in determining the so-called requirements of a system, in that (it) deliberately isolates the requirement process from technical and program realities. [Ref. 44:p. 6]

System requirements are determined from a number of stated user needs. Harold Chestnut suggests that requirements be generated from responses to such questions as:

1. What is the system to do?

    - Performance (size, weight, efficiency, appearance)
    - Cost (absolute, relative or competitive)
    - Time (when product is wanted, production time)
    - Reliability (life, failure rate, etc.)

2. What environment does it have to operate in?

    - Home, commercial, military
    - Power supply, variations
    - Maintenance, service
    - Physical (size, mechanical and electrical)
    - Existing equipment (what can/cannot be changed)

3. What environment is the product to be made in?

    - Engineering skills and facilities
    - Manufacturing skills and facilities

- What other products are being engineered and built
- What materials are available

4. What information is available?

- Given
- Required
- Known
- Unknown

5. What are the inputs?

- Signal sources
- Power sources
- Disturbances and noises
- Regulation of input sources

6. What are the output characteristics?

- Signal distribution
- Noise limitation
- Accuracy
- Loads and impedances of output [Ref. 45:p. 24]

To understand the importance of system requirements, designers often create scenarios that depict the system in its real world operating environment. Since the future is shrouded in uncertainty, many private and government industries rely on scenarios to help with system requirement analysis. Harold S. Becker states that scenarios can be used in three different capacities:

- To estimate if various policies and actions can assist or prevent the conditions of a scenario from coming about.
- To assess how well alternate policies and strategies would perform under the conditions depicted, i.e., to estimate risks in choosing certain courses of action.
- To provide a common background for various groups or individuals involved in planning within an organization. [Ref. 46:p. 96]

Scenarios typically cover a wide range of conditions, often encompassing such themes as: demographics, economics, technology, government legislation, political and social values and, "foreign situations and involvements." [Ref. 47:p. 99] The following list is an example of a systematic approach to scenario generation.

- Select the basic characteristic: the few conditions most important to shaping the system or marketplace being studied.
- Set the possible range of values that will be studied for the basic characteristics, if possible, in quantified terms.
- Select the number of scenarios that will be studied: combinations of the basic characteristics that are internally consistent and sufficiently plausible.
- Designate the indicators and trends that will be treated in each scenario.
- List important events: developments necessary for the conditions of each scenario to come about and those important to shaping the indicators and trends.
- Estimate probabilities of each event in each scenario and impacts of each of the indicators: likelihood of occurrence and influence on each other.
- Project the indicators: quantified values vs time.
- Prepare narratives: describe evolutions of conditions in each scenario spotlighting key events/developments, important trends, implications for the system or marketplace studied and, where possible, implication for strategies, policies and actions. [Ref. 48:p. 100]

Just as writers may suddenly suffer from "writer's block," similarly, authors of scenarios, may encounter mental blocks which could hamper analysis and creativity. The eight steps to scenario writing ensures that the scenario will always be consistent and logically oriented towards the requirements and objectives of both the users and system engineers.

a. Threat Specification

The word "threat" is defined as:

> The sum of the potential strength, capabilities, and intentions of an enemy, which an can limit or negate mission accomplishment or reduce force, system or equipment effectiveness. [Ref. 49:p. J-14]

Threat specifications can provide system engineers with important information that can be inputs into scenarios and simulations, and provide a realistic estimate of the threats which could impact the system once it is operational. The threat specification is generally developed within the intelligence community and validated by the Defense Intelligence Agency.

In addition to the physical attack threat, C3 systems can be subject to electronic threats, including jamming, spoofing, and exploitation, as well as nuclear related effects on communictions connectivity; and, nuclear induced upsets and radiation effects on electronic equipment.

3. Functional Analysis

The purpose of the functional analysis stage is to determine the functions and subfunctions of a system and how they are to be integrated in order to accomplish the overall mission. A good working definition of functional analysis states:

> Functional analyses serve as tools for defining areas of functional agreement, identifying functional requirements, determining interfaces among system components, highlighting system issues, and providing a basis for performing system trades and developing candidate architectures. [Ref. 50:p. 169]

In the design of an Anti-Air Warfare (AAW) weapon system, for example, the highest level functions to be considered would be target sensing and weapons

delivery. Subfunctions of these might include: command center functions, display console functions, radar system functions, communication system functions, and surface-to-air missiles system functions. Sub-subfunctions might include information gathering and processing from dissimilar sources, assignment of weapon launchers, or frequency assignment for the radar beacons. This breakdown of a system into functions and subfunctions is known as functional decomposition. It gives the system engineer a close, in-depth look at the functions which need to be incorporated into the design of the system. Another useful means to measure a system's ability to satisfy system performance requirements is through timeline analysis. In the case of the AAW weapon system, several functions must be performed before a target is engaged. The duration of these functions is critical because there might not be an existing system which can satisfy the time allocations for the weapons system's engagement requirements. For example, what are the set of decisions a commander executing his AAW mission needs to make to accomplish his mission? How much time can be allocated to each of these? How much time is needed to detect an inbound enemy target? How much time is needed to correlate tracks and assign a missile battery? How much time is needed to arm and launch a missile at an inbound enemy target? Once the quantity of time is established to perform these functions, system engineers can perform a timeline analysis to depict the sequencing of time-critical functions in order to identify bottlenecks and to validate proper performance. If the sensing function takes too long, or does not satisfy the intended requirements, system engineers would perform trade studies or exploratory

technology work would be needed to develop a faster sensor, processor, etc., which would satisfy the functional timeline requirements.

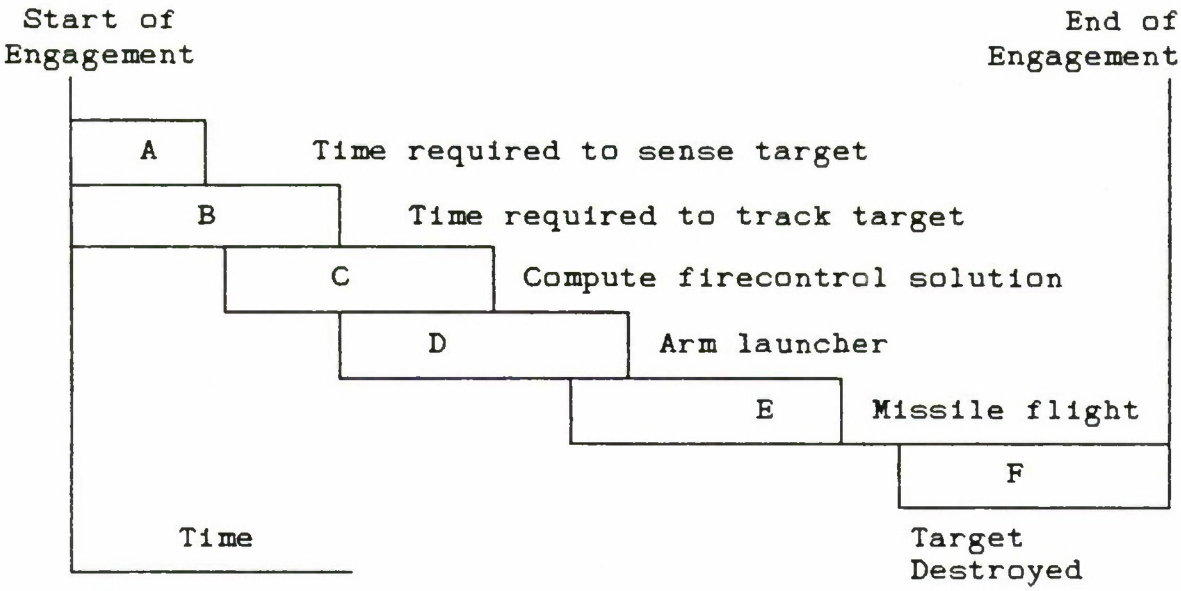
Figure 7 illustrates this process. Figure 7a shows the existing timeline for a missile engagement sequence. Figure 7b shows the required timeline to meet a faster more advanced missile threat. Timeline analysis is a useful tool to evaluate system performance.

4. Definition of Alternative Architectures

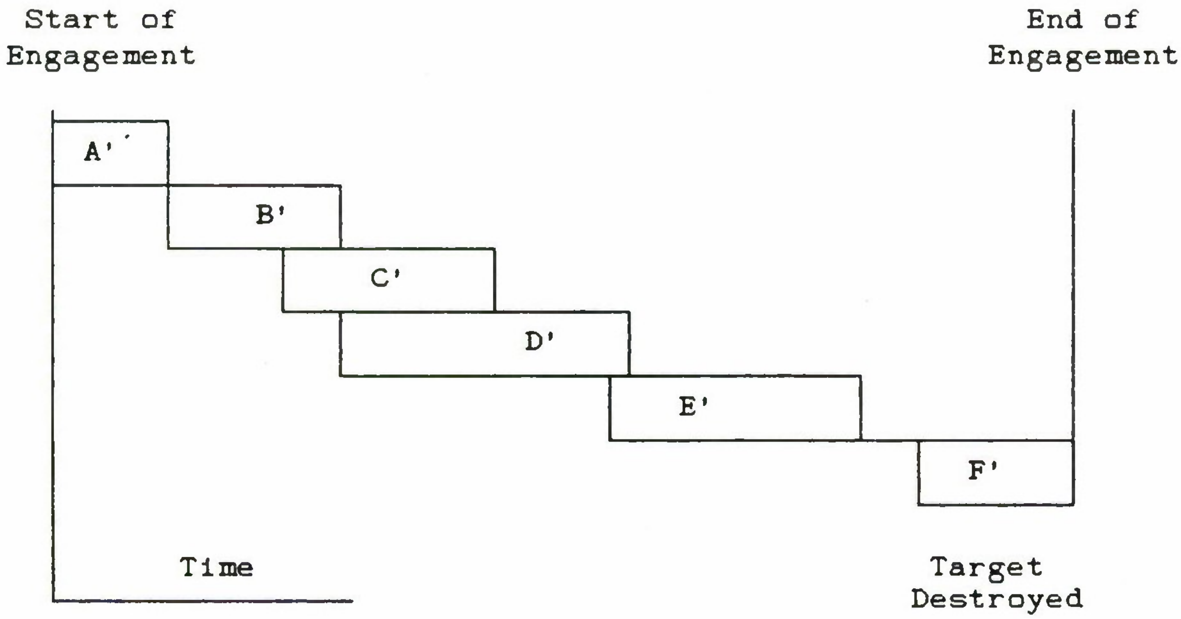
In general, architectures are simply "the structure of anything." [Ref. 51:p. 125] They represent the physical structures which could be designed to incorporate the mission objectives, system requirements and functional attributes needed for the development of a command and control system. The following are definitions of system architectures taken from Bethmann and Malloy's thesis, "Command and Control: An Introduction":

- A specific arrangement of basic elements (of a system) satisfying the required functions and boundary conditions of the system.
- An integrated set of systems whose physical entities, structure, and functionality are coherently related.
- A generic design which partitions combat systems into parts, describes their functions and defines the interrelationships between the parts. [Ref. 52:p. 125]

An experienced and imaginative system engineer can develop several solutions to fullfill the needs of a project's requirements. The more solutions that are generated, the greater the chances that a successful system will be engineered. An effective way to visualize the possibilites for defining alternative systems is to



(a)
Operational Timeline
Depicting an AAW Engagement
Using Existing Technologies



(b)
Operational Timeline
For Proposed AAW System

Figure 7.

AAW Engagement Timelines

construct an idea matrix as discussed in the preceding chapter. These alternative system architectures, then need to be screened and reduced in quantity to include only the most promising solutions.

The alternative solutions can be evaluated on the basis of performance, reliability, maintainability, schedule, cost, and other factors as appropriate. The system engineer must select the alternatives that best satisfies the user requirements in the specific threat environment.

5. System Analysis and Trade-offs

The following fable is an excerpt from Jean Pierre Protzen's article, "Reflections on the Fable of the Caliph, the Ten Architects and the Philosopher." This passage nicely illustrates the need for an objective approach to a scientific method of decision making when the instinctive decision skills of the designer alone are not enough:

Once upon a time, a great Caliph decided to have a new palace built. He summoned his ten architects and told them, "Within a month I want to see your plans. The grand vizier will disclose to you what the conditions are that must be satisfied and what requirements are to be met."

After a month had elapsed, ten plans were presented to the Caliph.

"Are these plans all identical?" asked he.

"They are all different." he was told.

"Are these plans compatible with each other?" he inquired.

"They are all irreconcilable." was the response.

"Is one of them inspired by the true art of building?" he wanted to know. "My plan is the only true plan!" the ten architects exclaimed in unison.

The great Caliph smiled and decided, "I will therefore choose the plan which best suits my desires."

On hearing the Caliph speak a venerable counselor shook his head and uttered, "Who will then defend the truth if the great Caliph does not?"

Disturbed by this observation, the Caliph summoned his philosopher to ask him, "Was I right or was I wrong to rely on my own judgement?"

"Did you great Caliph have any more reasonable ways to decide?"

"No." was the Caliph's response.

"Does the plan you chose still suit you?" the philosopher wanted to know.

"Yes, more than any other." the Caliph retorted.

"Would there have been any advantage in letting the dice decide?" asked the man whose mission it was to think in terms nobody else did.

"Are you jesting?" the Caliph burst out.

"Be assured, grand sovereign, there is not to my knowledge no reason why the Caliph should not have good judgement. Your decision was, and remains, idoneous."

"But truth--what about truth?" the Caliph insisted once more.

"I do not know." the philosopher said with emphasis, "who is more foolish, he who lets the dice roll, or he who reaches his decision by virtue of a truth he cannot recognize?" [Ref. 53:p. 3]

The Caliph resolved his dilemma over which plan for a new palace to select by exercising his idoneous judgement, where idoneous is defined as:

> what considers the conditions, what responds to the requirements, that which conforms to the ends and intentions, or what is appropriate to its functions.[Ref. 54:p. 3]

The moral of the fable suggests that all too often we are confronted with making a decision without knowing all the information necessary for a truly deliberated choice.

To reduce the scope of uncertainty designers use system analysis and trade studies which help to organize a concept's attributes into predictable and quantifiable measures, thus, allowing the decisions making process to be and objective process, rather than a hasty or uneducated choice.

a. The Trade-off Analysis Process

System analysis and trade studies are involved in all phases of a program. The primary role is in system synthesis and system optimization. The system optimization process starts with the previously defined feasible system architectures or conceptual designs. Each feasible architecture or design is, in turn, perturbed and the perturbed system evaluated. To determine whether the perturbed system is better or poorer, the system engineer requires criteria to measure optimality. In optimizing, the system engineer usually has to examine many criteria. Examples are technical performance, mission utility, system cost effectiveness, weight, power, schedule, risk, etc. Various figures of merit (FOM) or optimality criteria, are plotted against system design parameters, and engineering judgment is used to ascertain the relative importance of one criteria over another. The

sensitivity of FOMs to design changes is also evaluated, and the optimized design is iteratively approached.

By using a trade study, the Caliph could have reached a decision that would have not only satisfied the philosopher, but the ten architects as well. For sake of discussion, the author will suppose that the Caliph's new palace demanded the following requirements: A 10 ft wide moat for defense; a fortified ledge for his archers 8 ft wide; a large room for ceremonial functions 3500 sq ft; an indoor reflection pond and a maximum floor space area of 10,000 sq ft.

Once the plans were submitted it is presumed that every palace design incorporated these essential features. By conducting a trade study, the Caliph would be able to determine which palace design would be best suited for one of the several proposed contingencies: earthquake; enemy attack; or entertaining foreign dignitaries. Trade studies will help to demonstrate if the Caliph would have to give up one important aspect of his palace in order to successfully cope with a contingency. For example, if the palace came under attack, would fortified ledges be wide enough for his archers, and thus, impact the square foot allotment for his grand receiving room?

b. Modeling and Simulation

Modeling and simulation are two examples of tools which are important to system engineers. These methods permit system engineers to study the effects of various systems decisions or choices without going through the complete process of actually constructing and testing the idea being considered. The following

definitions of modeling and simulation were advanced by Harold Chestnut in his book System Engineering Tools.

- Modeling - a representation of a system or a part of a system in a mathematical or physical form suitable for demonstrating the way the system or operation behaves or may be considered to behave.

- Simulation - the subjecting of models to various inputs or environmental situations in such a way as to explore the nature of the results which might be obtained by the real system when experiencing these sorts of inputs and/or environmental conditions. [Ref. 55:p. 107]

Modeling and simulation are important tools to the system engineer. They are especially valuable in helping to understand the nature of the system during the formulation stages as well as the later stages of the design process. System engineers use an assortment of different modeling methods, such as process, performance, reliability, and cost models.

Process models tend to be qualitative models and are used to provide a pictorial representation of the elements which contribute to the overall system or equipment assembly. Performance models tend to be quantitative in nature. Performance models allow designers or system engineers to determine static or dynamic characteristics which aid in the refinement of equipment parameters, such as, signal flow or voltage variables. Reliability models determine the reliability of a system well in advance with a high degree of confidence. It is a quantitative approach which requires use of stochastic and statistical processes. Cost models emphasize points of an engineering process which are considered cost significant or cost insignificant. [Ref. 56:pp. 114-121]

Simulation may involve system hardware and its actual physical environment or it may involve mathematical models which define force or disturbance functions representative of the system conditions to be studied. Frequently, a detailed phenomenon associated with the particular equipment involved is checked out on a real-time or real-environment basis, so that second and third order effects from the phenomenon might otherwise be omitted from the model and carefully studied.

Simulations help system engineers in deciding whether or not it is advisable to proceed with system development with reasonable confidence in achieving successful mission goals. Through the use of increased simulations, alternative approaches can be studied in-depth prior to committing a given approach to detailed design and fabrication. Additionally, simulation gives system engineers the capability of studying where component failures, whether human or equipment, will be critical for degrading or aborting a system mission.

6. Concept Selection

This phase follows the results of the trade-off studies. It involves the selection of the most promising concepts from the several suggested solutions. Selection is not only based on the results of trade analysis, but also on the experience of the system engineer or the application of additional criteria. Systems today are increasingly complex so selection of the most suitable alternative should not be made through idoneous means. System engineers often depend on extensive trade analysis or trade studies which provide, "a structured, analytical framework for evaluating a set of alternative concepts." [Ref.57:p. 8-1]

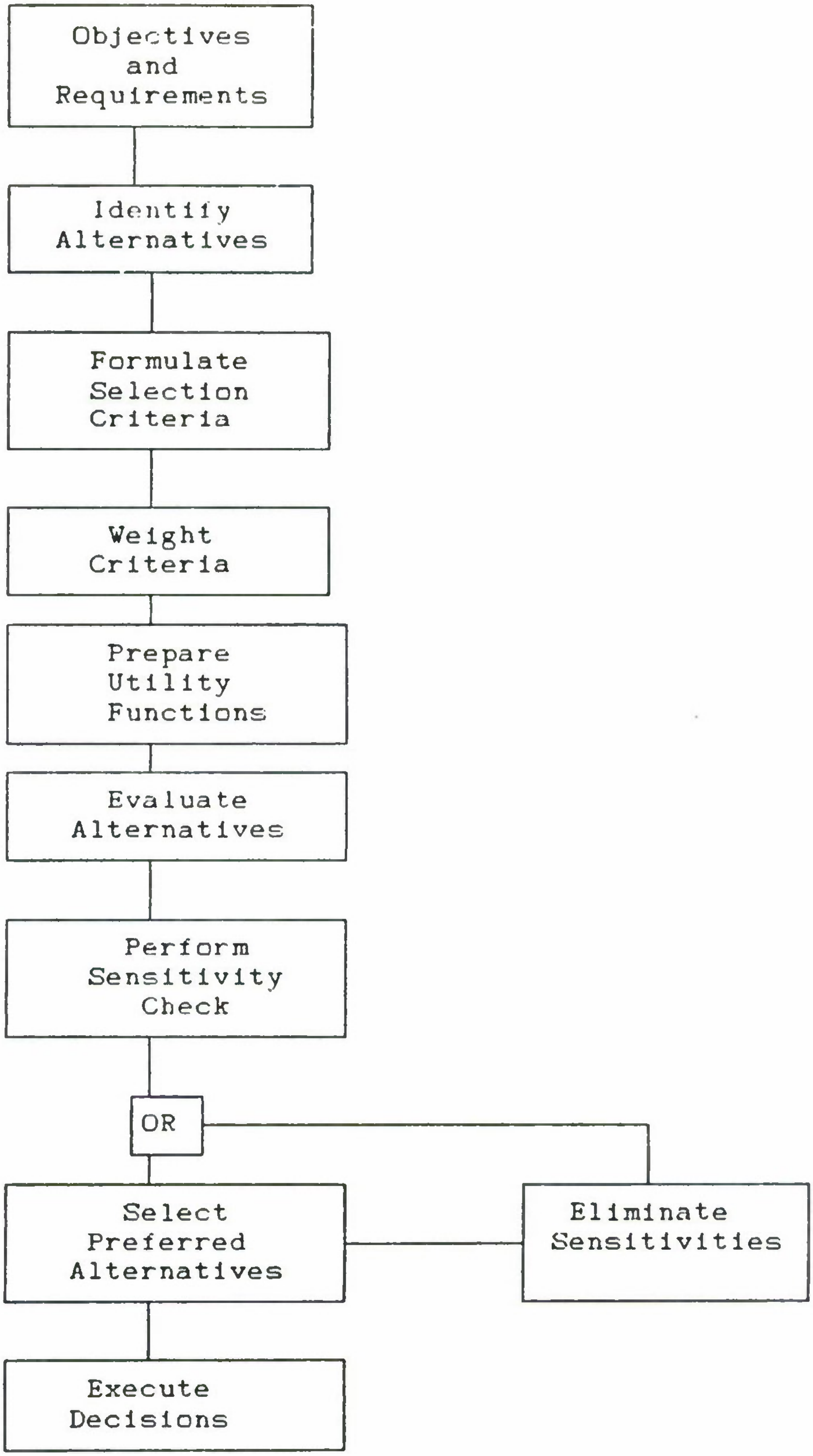


Figure 8.
(From Ref. 56)
The Trade Analysis Process

Figure 8 illustrates the basic steps of the trade analysis process as set forth in the System Engineering Management Guide. These steps are outlined and described in the following paragraphs.

Analysis objectives and requirements must always be expressed in an explicit manner. They should define the need, the user, and the availability of resources which bound the scope of the system being reviewed.

Identifying alternatives allows the system engineer to select from a wide assortment of possible solutions. These solutions are usually representative of existing, modified or designed systems architectures all of which incorporate some degree of functional promise.

> Candidates should reflect the widest possible range of distinctly different solutions if the overall goal of optimized system design is to be achieved. [Ref. 58:p. 8-3]

Selection criteria are standards for judging the systems overall ability to achieve a desired operational function. Ideal selection criteria have six attributes:

1. Differentiate meaningfully between alternatives without bias.
2. Relate directly to purpose of the trade off analysis, including established requirements and high interest concerns.
3. Be stated as broadly as possible.
4. Be able to be measured or estimated at reasonable costs.
5. Be independent of each other at all levels.
6. Be universally understood by evaluators. [Ref. 59:p.8-5]

After criteria are selected, they can be numerically weighted according to their relative importance. Numerical weights are given to reduce the effects of

evaluator bias on the trade study. Figure 9 depicts the weighted criteria associated with a ship design program. The numerical scale used is coincidental, provided that it is consistently distributed down in hierarchical fashion. In this example, criteria are classified by their relative contributions to mission capability including speed, endurance, logistics, cargo capacity, safety, and cargo capability. Utility functions are a useful way to translate diverse criteria to a common scale. For example, how does one compare speed (in knots) with endurance (in nautical miles)? By using utility curves, changes in the performance associated with a given criterion can be correlated into a utility value. Utility values typically range from 0 to 1. The range of utility curves encompass the range of acceptable alternatives. Utility curves can be generated using, "engineering judgement or a more quantitative approach." [Ref. 60:p. 8-9] Figure 10 illustrates one theoretical utility curve for ship speed. The utility value of an attribute is multiplied by the contributing weight of the attribute to determine the change in overall mission capability of the ship. [Ref. 61:p. 8-9]

Once utility functions have been established, the performance of each design alternative can be estimated with respect to each criterion.

> Performance estimates are produced by evaluators from testing, vendor sources, parametric analysis, simulation, experience, comparison, or other available, affordable, and dependable methods. [Ref. 62:p 8-12]

The scoring plan represented by utility curves can then be used to convert these performance estimates into effectiveness measures by assigning a score for each performance level. For example, an alternative evaluated as having an expected speed of 31.5 knots would receive a score of 0.5, while an expected speed of 33 knots would receive a score of 1.0. [Ref. 63:p. 8-12]

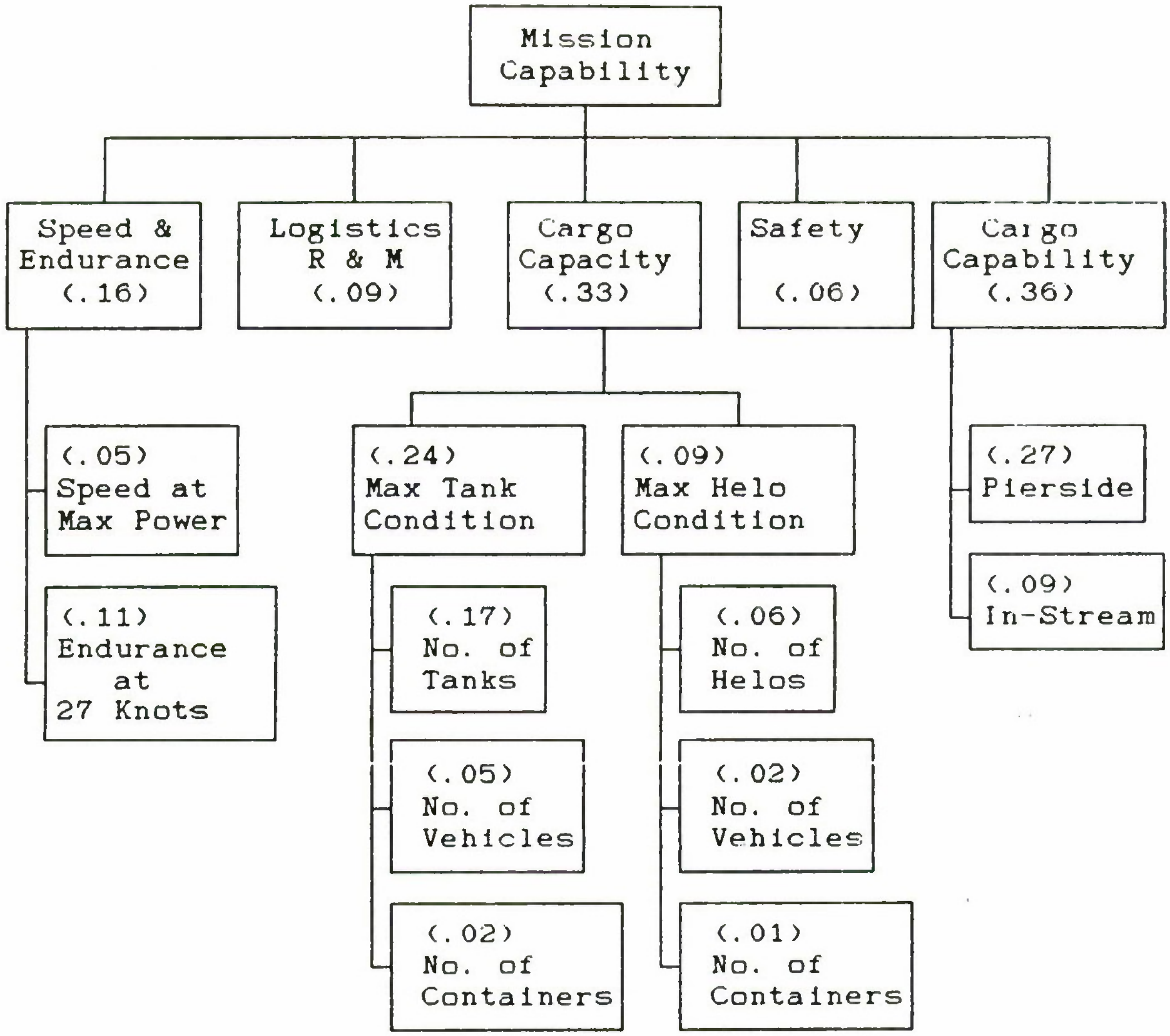


Figure 9.
(From Ref. 56)
Sample Weighted Criteria Table

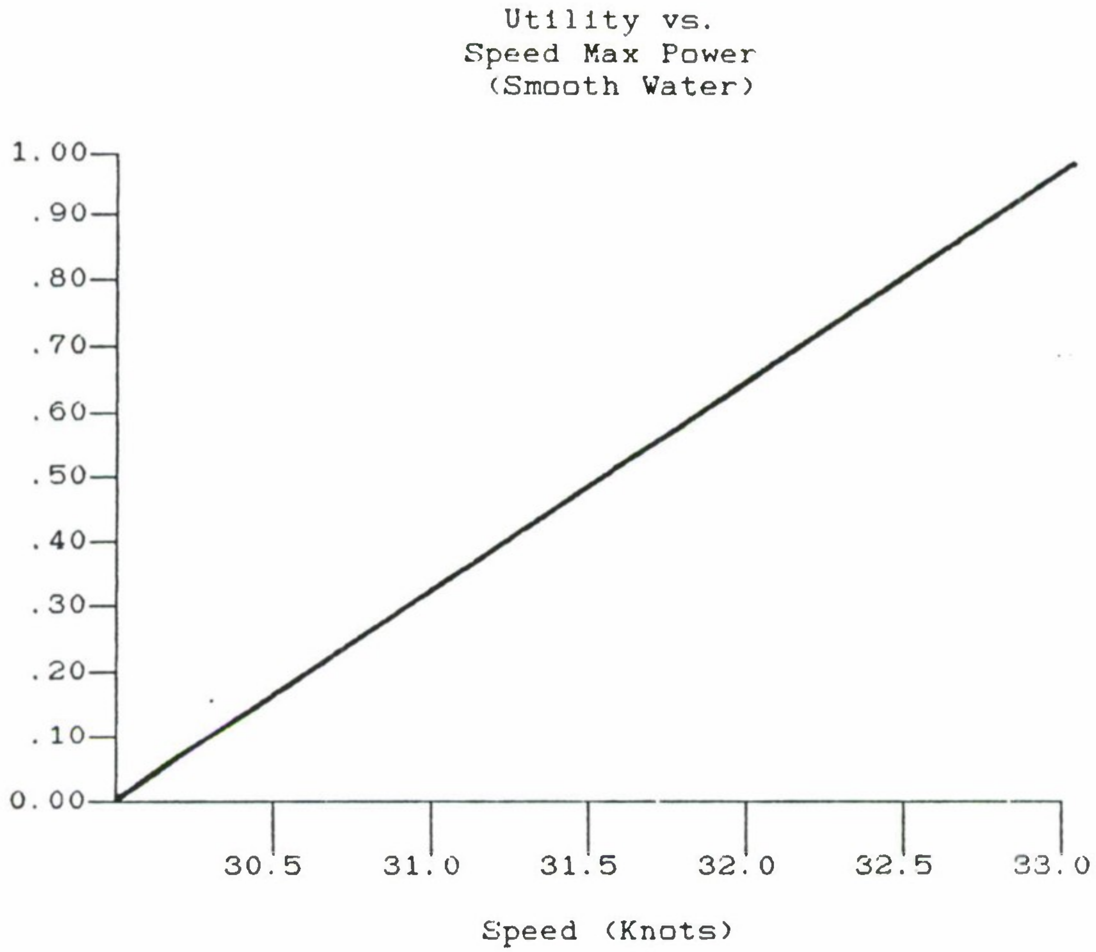


Figure 10.
(From Ref. 56)
Sample Utility Curve

A sensitivity check must be performed to enhance the confidence of the results to the decision maker. Where the total weighted scores of several alternatives are closely similar, "a small change in the estimated performance of any alternative against any criterion may change the decision." [Ref. 64:p. 8-12]

Trade studies of alternative design approaches begin to develop more detailed design solutions. Trade studies may confirm the original selection of system or subsystem elements, or seriously question their appropriateness or adequacy. As the design becomes more detailed, the degree of freedom for considering alternative design approaches decrease and the choice of solutions becomes more restricted. It is through trade studies that consideration is given to design features and characteristics which will facilitate the operational use of a system.

7. Concept Definition

This phase of the system engineering process takes the selected concept and formally defines and describes its performance, physical configuration and critical technologies. The concept definition phase helps system engineers understand the system not only in terms of physical relationships, but also in terms of postulated abilities. For instance, how will human operators interface with the system? How easy will input signals travel through the system without being distorted by gyro, servo or computer errors? System sizing addresses many aspects inherent to the system that were never considered up to this point because their level of detail was not necessary in the selection of the system concept. System sizing is therefore a phase which finely tunes and defines in detail all the functional requirements, subsystems, components and procedures in one integrated package.

a. *System Sizing*

System sizing attempts to define and document the physical subsystems and components, and the overall arrangement of the system design. Performance parameters, error budgets, hardware, software, displays, human factors and risk assessments are an example of some of the areas which contribute to the system's composition and generate realistic estimates of the expected volume of the system, its performance measures, functional interfaces and cost. The following are examples of some important cost-reducing criteria:

- Eliminate - Ask if this function is actually needed. There is nothing more precise and cuts costs more dramatically than the elimination of a part or assembly process all together.
- Simplify - What is the simplest possible way? Strive to utilize the least number of parts, with the simplest shapes.
- Duplicate - Think symmetrically. Does the design contain identical parts? It concerns making ten tools for ten parts of one tool for ten parts.
- Standardize - Does the system utilize off the shelf components? Do not custom design when you can buy ready made.
- Slow - Watch for high relative velocities; whenever possible, seek to reduce relative motion between parts. High velocities create high stresses, wear rates, generate heat, and create noise.
- Smooth - Cyclic variations in velocity create accelerations and dynamic loads which create a need for balancing, higher strength parts, more sophisticated bearings, vibration damping devices and special design considerations to combat fatigue, fretting and noise.
- Cool - Avoid extreme operating temperatures which tend to increase corrosion rates; reduce strength; deteriorate materials; and necessitate the selection of more expensive materials.

- Lighten - Weight is paid for by the pound. Excessive weight is costly in material cost, static and dynamic loading, oversized parts, increased costs in machining, handling, and shipping. [Ref. 65:p. 101]

b. Block Diagrams

The use of block diagrams are an important step in the concept definition phase because it enables designers to size subsystems and analyze component interrelationships. A block diagram is essentially a simplistic "wiring diagram" of the subsystems or components. These subsystems or components are usually represented by rectangular blocks with interconnecting lines. Block diagrams also provide a logical presentation of the system so that error budgets and other system related procedures can be easily referenced and functional interfaces specified.

c. Error Budget

There are many sources of error in large complex systems. In general, system errors are caused by dynamic lags, disturbances, electronic and manufacturing tolerances, aging, and variations caused by environmental changes. Manufacturing tolerances contribute to the error of all forms of systems. Practical considerations such as technological developments, cost, and schedule, require the engineer to specify components and equipment with finite tolerances. The systems engineer must consider all sources of error: dynamic, random and systematic. He must estimate the contribution of each source of error during the anticipated operating conditions, and then determine whether the estimated error contributions can be tolerated. A useful method for denoting anticipated errors is by means of

an error analysis. An error analysis describes the process of, "...estimating, negotiating, and computing the total system error." [Ref. 66:p. 37] After the various sources of error have been considered an error budget can be specified. In the event that a certain source of error exceeds its specified error after being developed, the system engineer must attempt to reduce other sources of error in the error budget to meet the required system performance.

d. *Human Factors*

The proper design of C3 systems requires as much understanding of human aspects as that of the equipment's characteristics. Human controllers have several unique characteristic. Man's input-output relationships cannot be described as being "purely linear, nonlinear, time variable, random or discrete." [Ref. 67:p. 134] Human controllers are actually a combination of all these traits. The following is a list of human characteristics which have been developed to explain human behavior in terms of a mathematical description.

- Frequency response - The human controller responds predominantly to low frequency commands. He tends to attenuate high frequency components where the attenuation increases with frequency.
- Nonlinearities - Man's behavior indicates distinct nonlinear characteristics. However, some of his characteristics may be linearized.
- Time Variations - The human controller displays time- variable characteristics. This is due to his adaptive capability which permit him to change his characteristics with time and his learning capability which changes his performance with time.
- Discreteness - The human controller's response indicates that he behaves as a discrete or sampled-data system.

- Delay - Man does not respond instantaneously and has a transportation lag associated with his response.

- Randomness - The variations of a human controller's performance in successive trials indicates random characteristics. The variation can be reduced with adequate training, motivation and simplicity of tasks.

- Adaptiveness - Man is a highly adaptive control system, able to adjust his characteristics with a wide range of controlled element dynamics, and able to learn and predict future actions of an input function.[Ref. 68:p. 134]

In addition the capability of man to perform critical functions under stress, particularly command decision making, and the human factors aspects of man-machine interfaces are critical to the definition and implementation of an effective C3 system.

e. Survivability

Survivability is an important characteristic of any system, especially for command and control equipment. Mission objectives must be accomplished, and in order to do so, command and control systems must be designed to withstand tremendous combat extremes. The inherently complicated nature of electrical equipment, its sensitive composition and packaging, make it vulnerable to enemy attack. Physical attack can destroy equipment: computers, transmitters, receivers, associated power scources, and heating and cooling systems. A widely used specification of C3 system survivability is that the C3 system be as physically survivable as the other system elements with which it must operate. Jamming and nuclear effects must also be taken in account.

It is also desirable that C3 systems degrade gracefully or be reconfigured. W. A. Demers, managing editor of Military Forum discusses in his

article "Ensuring Communication Survivability" four concepts relating to wartime command and control equipment restoral:

- Redundancy - Design critical command and control equipment with back-up power sources when it is both practical and cost-effective.
- Physical protection - Proper use of concrete revetments, and bermed soil, significantly reduce shrapnel and splinter hazards, and deflect overpressurization from explosions. Another way to make communications more survivable is to use the innermost core of multipaired cables for critical communications, the outer pairs for less critical communications.
- Spares and substitutes - Having enough restoration kits and prepositioned spares on site is the best insurance that communications repair specialists will be able to at least restore the system to a minimum capability.
- Rapid Repair Techniques - The ability to identify where a quick fix will be able to provide a temporary, if degraded, capability is something that can be instilled through training. [Ref. 69:p. 54]

f. Maintainability/Availability

The maintainability of a system is a very important factor in the overall engineering of a system. Maintainability is concerned with the monitoring, checkout, corrective procedures, and preventive measures concerned with systems operation. The following is a generally accepted definition of maintainability described in Wilton P. Chase's book, Management of System Engineering:

> Maintainability is the characteristic of the system equipment that permits ease and economy in accomplishing all maintenance functions. This includes such things as ease of servicing and of removal and replacement of components, rapid fault isolation, failure prediction and minimum personnel skill levels for maintenance tasks. [Ref. 70:p. 41]

Maintainability is therefore a function of the equipment's design, the operating personnel, and the support facilities. System maintainability can be

improved by providing accessible test points, built-in test equipment, and built-in diagnostic aids; training in the operating personnel; and providing spare parts and equipment for incorporating repairs. [Ref. 71:p.66]

Availability is a measure of the degree to which an item is in an operable and committable state at the start of a mission when the mission is called for at a random time. Availability is defined in terms of time-related factors of reliability and maintainability as follows:

- Mean-Time-Before-Failure (MTBF) is a reliability function which assumes that operation occurs after early failure (infant mortality) and prior to wear-out, i.e., a constant failure rate exists.
- Mean-Time-To-Repair (MTTR) is a maintenance function, can include corrective maintenance time (CMT) and preventive maintenance time (PMT).
- Mean-Logistics-Down-Time (MLDT) is a maintenance related logistics function which involves spares provisioning and includes logistic delay time and administrative delay time. [Ref. 72:p. 16-2]

Inherent Availability (Ai) can therefore be expressed as:

Ai = MTBF / MTBF + MTTR cmt [Ref. 73:p. 16-2]

g. *Schedule With Milestones*

The cornerstone of good program management is that systems be developed within prescribed cost and schedule estimates. DOD Directive 5000.1, "Major and Non-Major Defense Aquisition Programs establishes the acquisition phases and milestones decision points used to manage major defense acquisition programs. In addition to these major milestones, detailed schedules with

development must be defined for all technology, subsystems, and system developments.

Since large scale systems costs involve large amounts of money, people, and materials, additional time spent in one development area may result in large cost increases being incurred by the overall project. It is therefore imperative to define schedule milestones, both as a means for decisions on whether or not to continue system acquisition, as in DOD 5000.1, but also to allow the achievement of required system capabilities within cost goals.

8. Concept of Operations

An interactive phase of the system engineering process with prospective users, consists of developing operational descriptions of how the system will perform in the, test and evaluation phases, and operationally when deployed in the field. Common to most concept of operation documents are four areas of consideration:

- Concept of operation,
- System deployment,
- System employment or system support, and;
- System readiness.

The first area of a system's concept of operations describes day-to-day peacetime, crisis, or combat operations. It consists of a time-sequenced narrative of the systems operations.

System deployment covers the plans for fielding the system, and includes such questions as a system survivability, sustainability, interoperability and

transportability. For instance, the transportability of a system would not only explain the logistics involved in moving a system, but also consider alternative transportation means and routes in the event a primary method fails.

The employment concept defines the strategy, doctrine, plans and procedures used in employing the system. Also considered is system transition from a peacetime mode of operation to a combat mode of operation. The employment concept considers recovery and reconstitution operations, where recovery is the transition of a system from wartime to peacetime operations, and reconstitution is the required level of repairs and maintenance that is necessary to ensure the system is functional.

The last area of a concept of operations is support or system readiness. Issues involving logistics, safety, personnel, training, and tests and exercises are all addressed.

D. SUMMARY

The system engineering process is an elaborate chain of iterative procedures which when carefully applied yield solutions to complex problems. The fact that this process is an iterative one helps to ensure the development of a system that is sensitive to all requirements and that is functionally correct.

The system engineering process that was described by Professor Donald Lacer in his course, CC4003, C3 System Engineering, covered eight separate stages. Mission need essentially describes the aims of the project to be engineered. It is a discussion of objectives and mission related criteria which system engineers use as

a template for the system engineering process. The requirement analysis and functional analysis phases together take the various operational objectives from the mission need stage and convert these inputs into either specific needs or well defined component interrelationships, respectively.

The experience of the system engineer and the needs of the user combine together during the alternative architecture stage. Here, the various alternatives are considered, each of which is a different arrangement of system requirements and components, that will eventually perform the stated mission objectives.

Trade-off analysis is a critical stage of the system engineering process. The system engineer must weigh each alternative according to various criteria which contribute to mission capability, program costs, system survivability, etc.

Concept selection entails the selection of the most suitable system alternative that is most representative of the user's needs. It is a selection that is based on the results of the trade-off analysis and permits system engineers to make objective decisions.

Concept definition defines and describes the critical technologies which will be incorporated into the design and development of the total system. The concept definition phase helps system engineers to study the selected system's physical relationships.

The concept of operations defines the system's expected employment and deployment characteristics, in addition to, related operational concerns such as system readiness.

The concept of operations defines the system's expected employment and deployment characteristics, in addition to, related operational concerns such as system readiness.

Each phase of the system engineering process involves a seemingly complicated assortment of procedures, but when closely examined, these procedures are simple, logically formulated tools which help integrate the expertise of the many divergent and technically oriented fields into one mission: the design and development of a system.

Chapter IV will examine the system engineering process for a mobile command post. The term project entitled, CINCCENT Ground Mobile Command Post will, be used to illustrate the various system engineering stages as discussed in Chapter III. The chapter will serve to apply the theoretical concepts this chapter has presented and provide the reader with an understanding of how these concepts are used.

IV. CINCCENT GROUND MOBILE COMMAND POST: A CASE STUDY

A. OVERVIEW

This chapter will bring together the concepts that have been discussed, thus far, by placing emphasis on the systems engineering approach to command, control and communications systems design. A case study entitled, "CINCCENT Ground Mobile Command Post," a term project developed for course CC4003 (C3 Systems Engineering) will be used to provide a specific example of the techniques discussed in this thesis.

The mobile command post will serve as an alternative to CENTCOM headquarters at MacDill AFB. The command post must provide a facility that is survivable, mobile, transportable and durable. The facility will be capable of establishing communications to link the battle staff with NCA/JCS, the MacDill Headquarters, airborne command post, Commander-in-Chief Central Command (CINCCENT) command center, service component and subordinate unified command centers, alternates and nuclear CINC's and surviving forces.

B. FUNDAMENTAL DEFINITIONS

The top level definitions of command and control are defined below to give understanding of the inherent characteristic of C3 systems:

- Command and control - is the exercise of authority and direction of a properly designated commander over assigned forces in the accomplishment of the

mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning directing coordinating and controlling forces and operations in the accomplishment of a mission.

- Command and control system - The facilities, equipment, communications, procedures, and personnel essential to a commander for planning, directing and controlling operations of assigned forces pursuant to the mission assigned. [Ref. 74:p. 77]

- Command center - A facility from which a commander and his representatives direct operations and control forces. It is organized to gather, process, and analyze, display, and disseminate planning and operational data and perform other related tasks. [Ref. 75:p. 4]

Most C3 system engineers would agree that human decision makers are the most important element of a C3 system. The C3 process, with man as the central focus, is represented in the O-O-D-A loop, Figure 11, developed by Col. John Boyd; and described in his work, Patterns of Conflict. It depicts four functions which are driven by the state of the environment: observe, orient, decide, and act. [Ref. 76:p.27]

Andrew P. Sage, author of "Human Information Processing Principles for Command and Control," states that military commanders in C3 environments perform the following decision and problem solving activities:

- Recognition and assessment of a decision situation - In which the need for a decision is recognized, and information requirements for the decision situation are identified.

- Formulation of the decision problem - In which the needs and objectives associated with a perceived decision need are identified and potentially acceptable alternatives are identified or generated.

- Analysis of the alternative decisions - In which the impacts of the identified options are evaluated.

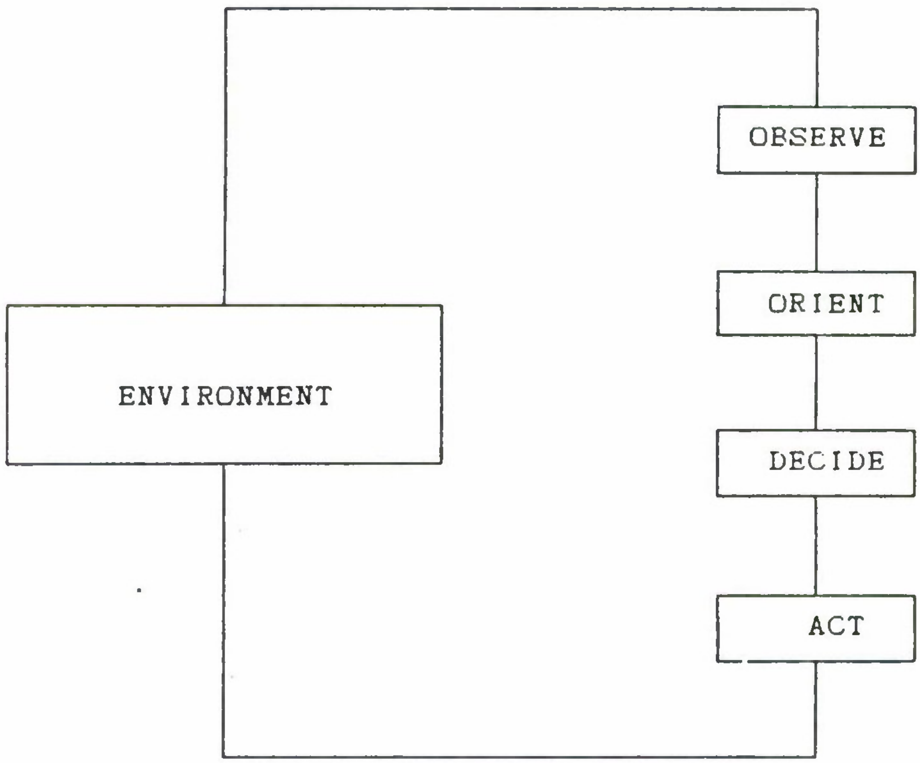


Figure 11.
Boyd's O.O.D.A. Loop
(From Ref. 75)

- Interpretation and selection - In which the options are compared by means of an evaluation of the impacts of the alternatives. The most acceptable alternative is selected for implementation or further study in a subsequent phase of decision making.

- Specification of decisions, plans and architectural structures - In which the selected alternative is further developed or expanded conceptually such as to yield specifications for activities to be undertaken.

- Identification of operational priorities - In which the conceptual plans and there specifications are decomposed to yield specific operational activities.

- Forecasting, Explaining and describing to others - Such that those who need to know information about a selected course of action are provided this information.[Ref. 77:p. 57]

Military commanders typically can perform these activities on an intuitive level, or in analytical fashion depending upon whether the initial problem or situation is familiar or not. Experience is an important characteristic a commander can possess because it is experience alone that may often dictate the proper course of action in decision making.

C. CINCCENT MISSION NEEDS

The purpose of a mobile command post for any unified commander is to support the mission of the CINC. The missions of the mobile command post as set forth by the Joint Chiefs of Staff are as follows:

- Maintain the security of the command and protect the U.S. and its possessions from aggression.

- Maintain the readiness of the command and its ability to carry out assigned missions and tasks.

- Assign and coordinate tasks among subordinate commands and ensure unity of effort.

- Communicate directly with the Secretary of Defense; Chairman, Joint Chiefs of Staff; Service Chiefs, subordinate elements and supporting agencies.
- Keep Chairman, Joint Chiefs of Staff, promptly advised of significant events that occur in areas of responsibility.
- In a major emergency assume operational command if forces in the area previously assigned by the Joint Chiefs of Staff Warplans.
- In limited action (short of war) exercise direct operational command of subordinate elements at any echelon in the chain of command. [Ref. 78:p. 13]

In addition to these general CINC mission needs, consideration for other, more operationally specific needs for the CINCCENT area have been defined:

- Deny Soviet expansion,
- Safeguard Western access to oil,
- Assure the security of allies and friendly states,
- Promote political stability, and;
- Assure the security of allies in the region. [Ref. 79:p. 13]

These needs represented the pertinent mission objectives for CINCCENT to perform within his area of responsibility (AOR). From the discussion of these needs came a realization of the requirement for additional components, which would support intelligence gathering, diplomatic assistance and in-theater communications.

D. CINCCENT REQUIREMENTS ANALYSIS

The mobile command post must have a myriad of specialized equipment that is designed to support CINCCENT and his staff in the accomplishment of their mission. The generation of requirements is based on the mission need with

considerable attention focused on command, control and communication components.

1. Required Capabilities

The mobile command post and the assigned personnel must accomplish all the mission requirements of a staff in support of the commander. A critical requirement for the staff is updating the commander on status of his forces. The staff must monitor the current situation, including the status of the U.S., our allies, and the threat in the area of operation.

Based on the situation in the area, the command post must have the capability to formulate responses to warning and threat assessment. This includes options, employing forces and executing operations plans. Once a plan is set in motion, the command post must continue to update the situation.

After an operation the command post must perform attack, strike, damage and residual capability assessments. These assessments will assist in future planning. Additionally, current status can be updated and effectiveness of tactics determined.

Once the assessment of an action is completed the command post will redirect forces as needed. If forces need realignment, based on losses, the command post will assist in reconstitution of the forces. The process of monitoring and assessing will continue as long as the operation continues.

When a mission is completed the command post will aid in termination of hostilities and any active operations. The command post must continue to prepare for future operations and redeployment of its forces.

2. Specific Communications Requirements

The CINCCENT mobile command post must be capable of maintaining communications while in transit from CONUS to allow for current force status monitoring and emergency action message receipt. Other requirements include:

- An integral, highly transportable set of modular communications equipment to support CINCCENT mission.
- Capability to maintain direct communications, connectivity and conferencing capability with NCA/JCS, CINCCENT forces and other unified and specified commands.
- Communications in place to assume the role of a primary communications node as a back-up to headquarters facilities.
- Interfacing with diplomatic communication systems and tactical theater and force organic communications systems.
- Access to CENTCOM forces without relying on vulnerable, peacetime communication nodes and switches.
- Direct access to ammunition storage points. (including nuclear forces)
- Automatic data processing to provide assistance to the battle staff in force management. This system must store national and theater level data bases, be user friendly, and interface with other command syatems.
- Receive, store, process, and display environmental data. This will require appropriate hardware and software to link with environmental databases either at the Fleet Numerical Ocean Center or the Air Force Global Weather Center. [Ref. 80:p. 21]

3. Additional Requirements

In addition to the above mentioned capabilities, the mobile command post must also be capable incorporating the following performance criteria into its design.

a. Durability

The CINCCENT mobile command post must have sufficient size and facilities to accommodate and support a battle staff. The battle staff must be capable of uninterrupted direction of operations and continuance of essential function necessary to sustain command and control of strategic and non-strategic forces. The command post must include battle staff facilities, executive aids, automatic data processing, essential maintenance and house-keeping support to sustain operational capability for 180 days.

b. Capability

The command post must be immediately responsive to a crisis situation and require minimum time to achieve full operational status. The command post must provide essential direction and guidance to subordinate commanders through the full range of mission requirements. This range includes peacetime through conventional and non-strategic nuclear warfare to execution of psychological warfare and protracted nuclear conflict.

c. Survivability

The command post must offer a high probability of survivability and endurability. These attributes come form mobility, concealment, and dispersion. The command post must provide access to CENTCOM forces without reliance on critical peacetime communication systems. Once fixed gateways are lost, the command post must interoperate with ground mobile forces. The command post

must have the capability to direct reconstitution of inter-theater communications networks.

d. Mobility

The command post must be easily deployable by ship or air transport. Additionally, the command post must be able to redeploy once in the forward area. CINCCENT must have ready access to forward troops so that he may observe the situation as he deems appropriate.

e. Human Factors

In designing the system, the role of human decision makers must be the center of focus. The purpose of the command post is to allow the staff to assist the commander in making decisions. Such items as information displays and decision support system, must address the potential for cognitive bias and the conflict with perception and reality of available information. The level of automation required must be weighed against the mobility, survivability and flexibility considerations. Additionally, group decision making versus individual decision making must be addressed.

f. Flexibility

The command post must allow flexibility so that staffs may react to situations. The command post must be able to expand or shrink to allow additional assets to be added or taken away. The command post must be able to react to difficult communications or reduced capability.

4. Threat Specification

The purpose of this section is to present the order of battle for the CINCCENT mobile command post. The following paragraphs will portray the external threats to a command post deployed in the region. These threats cover the entire spectrum from dismounted ground assaults to theater range, ground-to-ground missiles. The primary focus will be the Iranian military in the year 1999. The author has assumed that the Iranian military has been resupplied by extensive purchases from the Soviet Union. Furthermore, old U.S. weapons from the era of the Shah and systems purchased on the world market will be included. This summary of threats to our facility will not be complete. Full coverage of the enemy threat would fill hundreds of pages. Weather will not be covered since it is generally "neutral". But, U.S. planners must take into account the many challenges that this region will hold for the support of men and equipment. In addition, this area presents unique problems in the maintenance of internal and external communication links. Finally, the assumption is made that the Iranians will not independently develop nor the Soviets supply a 'wonder weapon' which might drastically change the arms balanced in CINCCENT's area of responsibility.

a. Ground Assault

A ground attack against the command post is the greatest danger. The Middle East is a region filled with terrorist and semi-military organizations. Dozens of these groups have no true love for such a symbol as the mobile command post. This facility is not a large organization which has sufficient manpower to establish and maintain a secure perimeter defense.

A small force of lightly equipped hostiles could attack the command center with satchel charges or stand-off rocket propelled grenades. Such attacks may be executed by specialized troops whose mission is to attack without warning prior to the outbreak of general hostilities. Another scenario may have pro-Shiite revolutionaries initiating these attacks without official Iranian sanction. In any scenario, to properly secure the command post for any extensive period of time would require external support from the host nation or U.S. combat troops.

b. Air Attacks

This command post will not deploy with organic air defense protection. The air defense coverage for the facility will have to be supplied by the host nation. Furthermore, the command post must make extensive use of such passive defense measures as "dummy" sites and all forms of camouflage. The Iranian air force could fly from military airfields located near Bandar Abas, Chah Bahar, Bushehr, Ahvaz or Shiraz. In addition, an extensive network of smaller airfields have been built to disperse the air force.

Current export versions of many advanced Soviet aircraft have been supplied to the Iranians. The mobile command post will be vulnerable to these aircraft. One example is the SU-24 fighter bomber. With a combat range of over 1100 miles, this aircraft could attack the command post in virtually any location in CENTCOM. The SU-24, similar in capabilities to the American F-111, is capable of carrying electro-optically guided smart bombs and cluster type munitions. These munitions will greatly enhance the probability of a successful attack. Short range raids at distances of 250 miles could be launched by both the Mig-21 and Mig-27 at

speeds of up to mach 2.0. This would allow little time for intercept by allied sea or land based fighters. The following is a list of Soviet-made fighter aircraft currently deployed in the Persian Gulf:

- Mig-21 "Fishbed" - Range: 925Km - Role: Fighter
- Mig-27 "Flogger DJ" - Range: 1200Km - Role: Ground Attack
- SU-24 A/C "Fencer - Range: 1800Km - Role: Fighter/Bomber [Ref. 81:p. 16]

Although suffering heavily during the long Iran-Iraq war, some U.S. equipment survived. These aircraft include older versions of the F-14A with Phoenix missiles, F-5E's and F-4's and F-4D's and F-4E's.

c. *Location*

To be destroyed, the mobile command post must first be found. The Iranians may receive help in locating the command post from a variety of sources. These sources include Iranian agents or sympathizers in the host nation, Soviet electronic gathering services, the international and domestic press or from Iranian direction finding equipment. The Iranian military has three separate, semi-mobile direction finding systems. These systems do not include their fixed sites located closer to the Iraqi border or older U.S. equipment along the Soviet border. The Iranian semi-mobile systems include the Fix series (HF frequency), Loop 3 (HF/DF) and the Ring series (HF/DF). Once located by the direction finding systems, the command post will become vulnerable to attack form the full spectrum of Iranian assets.

d. Nuclear, Biological and Chemical Warfare

It is assumed that the Iranians have not acquired nuclear weapons by the late 1990's. The Iranians have used chemical weapons. Chemical weapons are easy to produce. Some of the problems with these weapons is finding the best delivery system and handling the difficulty of their rapid decay in the desert heat. Although not efficient for all types of targets, chemical weapons may be "sprayed" from aircraft or air dropped in canisters. The Iranians do have the capability to deliver chemical munitions by means of rockets. These missiles may range throughout the Persian Gulf. But, this method of attack is far from an effective way to hit a target other than point targets. Unfortunately, the CENTCOM mobile command post is such a point target and could be effectively neutralized if attacked with a persistent chemical warhead.

e. Ground-to-Ground Missiles

If the Iranian military would like to strike land targets in the Persian Gulf they do have the ability. This type of strike would only take place in a major conflict. The Iranian stocks of long range ground-to-ground missiles are limited. The Soviet Union has avoided selling missiles which might be considered in the strategic missile category. Their sales have been exclusively theater ranged missiles down to tactical rockets. We assume that this policy will still be in effect and the Iranians are not sold a "long range" missile. The ground-to-ground missiles that the Iranians could possess are listed below:

- SS-1 B "Scud" - Range: 80-150Km - Guidance: Radio

- SS-2 C "Scud" - Range: 80-280Km - Guidance: Intertial
- SS-21 "Scarab" - Range: 120Km - Guidance: Intertial [Ref. 82:p:18]

All of these missiles may carry high explosive or chemical warheads. They were used frequently during the Iran-Iraq war against ground forces. They Iranians operated dozens of Chinese made Silkworm missile site located predominately in and around the Straits of Hormuz.

f. Summary

The mobile command post will be a vulnerable target. In particular, this command post will be a symbol of American intervention and consequently open to attack simply for being such a symbol. The greatest threat to the command post will be from a ground assault. The damage that a handful of determined and well equipped soldiers (or terrorists) may cause against such a target as a mobile command post is great. Once the command post is located by the enemy it will become vulnerable. Attack by aircraft or missiles is possible, but only in the context of a general war between Iran and the United States.

E. FUNCTIONAL ANALYSIS

The CINCCENT mobile command post has five functional areas of responsibilities, they are: Personnel, Combat Intelligence, Combat Operations, Information Flow, Logistics and Communications Management. Each of these areas can be further separated into smaller more specialized activities which support one of the main functions of the command post.

1. Mobile Command Post Functional Decomposition

The following lists the complete functional decomposition of a mobile command post.

1.0 PERSONNEL (J-1)

1.1 Planning: Managing Personnel

1.1.1 Monitor subordinate strengths
1.1.1.1 Ensure efficient administrative procedures
1.1.1.2 Maintain records on the collective status of forces in the command.
1.1.1.3 Establish battle and non-battle casualties in coordination with J-3.
1.1.2 Establish replacement procedures for command
1.1.2.1 Determine replacement requirements, present and anticipated.
1.1.2.2 Plan and coordinate procurement of replacements.
1.1.2.3 Develop a plan in coordination with J-3 for the receipt, processing, and movement of replacements.
1.1.2.4 Supervise the processing and movement phase and coordination of personnel audits to ensure efficient utilization.

1.2 Operations: Managing Personnel

1.2.1 Procure personnel
1.2.1.1 Identify specific requirements
1.2.1.2 Recruitment
1.2.2 Classify personnel
1.2.2.1 Evaluate qualifications.
1.2.2.2 Reclassify as necessary.
1.2.3 Assignment
1.2.3.1 Ensure effective utilization (Transfer, Reassignment, Separation)

2.0 INTELLIGENCE (J-2)

2.1 Planning: Intelligence

2.1.1 Higher level agencies tasking
2.1.2 Establish list of strategic targets
2.1.3 Establish imagery requirements
2.1.4 Determine mapping requirements
2.1.5 Prepare HUMINT and SIGINT collection plans
2.1.6 Develop reconnaissance/surveillance plans
2.1.7 Supervise/monitor collection activities

2.2 Process information and produce intelligence

2.2.1 Record information received
2.2.2 Evaluate/analyze information
2.2.3 Disseminate raw data to subordinates as required
2.2.4 Produce tailored intelligence for subordinates
2.2.5 Support J-3 on OPSEC and COMSEC
2.2.6 Establish intelligence liaison with host country

2.3 Operations: Intelligence

2.3.1 Conduct joint intelligence activities
2.3.1.1 Establish joint intelligence center to monitor collection activities
2.3.1.2 Define essential elements of information
2.3.1.3 Task organic collection assets
2.3.1.4 Conduct joint level SIGINT
2.3.1.5 Update target list
2.3.1.6 Update enemy estimate
2.3.1.7 Monitor OPSEC/COMSEC
2.3.1.8 Establish SI communications linked with higher and subordinate commands.
2.3.2 Collection of intelligence
2.3.2.1 Task organic assets
2.3.2.2 Task theater/national assets
2.3.2.3 Conduct SIGINT collection
2.3.2.4 Direct reconnaissance/surveillance activities
2.3.3 Analyze Intelligence
2.3.3.1 Monitor ongoing enemy actions
2.3.3.2 Maintain I & W
2.3.3.3 Develop estimates of enemy capabilities
2.3.3.4 Develop estimates of enemy intentions
2.3.3.5 Analyze SIGINT and EW collections
2.3.4 Conduct counter-intelligence
2.3.4.1 Monitor COMSEC/OPSEC
2.3.4.2 Conduct active HUMINT operations
2.3.5 Disseminate intelligence
2.3.5.1 Maintain all source intelligence
2.3.5.2 Disseminate intelligence to subordinates
2.3.5.3 Report to higher echelons

3.0 COMBAT OPERATIONS (J-3)

3.1 Planning Combat Operations

3.1.1 Produce contingency plans and update
3.1.1.1 Review system information
3.1.1.2 Determine requirements
3.1.1.3 Coordinate with/staff section - assign tasks
3.1.1.4 Receive and analyze input
3.1.1.5 Approve plans
3.1.1.6 Monitor higher/adjacent unit planning
3.1.1.7 Assess re-evaluate plans
3.1.2 Plan Tactical Operations
3.1.2.1 Receive initiating directive and planning information from all planning agencies
3.1.2.2 Analyze mission and review system information
3.1.2.3 Determine information requirements
3.1.2.4 Coordinate with staff and supporting agencies, request input
3.1.2.5 Receive and evaluate information and intelligence
3.1.2.6 Receive and develop planning guidance
3.1.2.7 Develop course of action
3.1.2.8 Prepare estimates of supportability
3.1.2.9 Disseminate commander's concept of operations

3.2 Operations

3.2.1 Supervise conduct of operations
3.2.2 Direct command center and combat operations
3.2.2.1 Supervise execution of commanders decisions
3.2.2.2 Receive and review subordinate unit plans
3.2.2.3 Update estimate of situation
3.2.2.4 Furnish guidance
3.2.2.5 Monitor & display friendly unit movement
3.2.2.6 Monitor & display tactical operations
3.2.2.7 Evaluate friendly and enemy forces after engagements
3.2.2.8 Continuous planning
3.2.2.9 Prepare & submit reports for higher authority

3.3 Information Flow

3.3.1 Receive, display, and retain incoming information
3.3.1.1 Receive, review, and analyze information
3.3.1.2 Display incoming information
3.3.1.3 Initiate appropriate action
3.3.2 Prepare reports, studies, and information
3.3.3 Disseminate reports, studies, requests & orders

4.0 LOGISTICS (J-4)

4.1 Planning

4.1.1 Coordinate with component service support groups the collection of logistics requirements for each element based on CINC's course of action.
4.1.1.1 Collate requirements
4.1.1.2 Resolve shortfalls among adjacent and higher HQ
4.1.2 Oversee the preparation of logistics plans
4.1.3 Coordinate the reserve material program for assigned forces
4.1.3.1 Monitor weapons package build-up (e.g., at weapons stations)
4.1.3.2 De-conflict load-out schedules
4.1.4 Coordinate the development of interservice support and host nation support agreements
4.1.4.1 Coordinate the employment of service component construction forces
4.1.4.2 Coordinate strategic mobility requirements to include external transportation
4.1.5 Monitor War Reserve & Sustainability Requirements
4.1.6 Plan for future operations
4.1.6.1 Coordinate with J-1, J-3, J-2, to determine those operations or intelligence activities which affect logistic planning, availability of support assets, etc.
4.1.6.2 Develop logistics concepts in support of future operations & develop courses of action
4.1.6.3 Conduct estimates of supportability and provide logistic decision recommendations in support of future operations

4.2 Operations

4.2.1 Execute interservice support and host nation support agreements
4.2.1.1 Monitor to ensure compliance
4.2.1.2 Coordinate, validate, consolidate requirements for use of MSC, MAC, and Military Transportation Management Command
4.2.1.3 Deconflict transportation issues

4.2.2 Monitor equipment & supply status
4.2.2.1 Coordinate external & supply maintenance
4.2.2.2 Monitor resupply
4.2.2.3 Resolve distribution of assets where problems exist
4.2.2.4 Analyze impact of shortfalls
4.2.2.5 Prepare alternate plans for reaction

5.0 COMMUNICATION MANAGEMENT (J-6)

5.1 Planning

5.1.1 Plan for installation, operation, and maintenance of communication systems
5.1.1.1 Establish maintenance plans, establish liaison with higher, adjacent, and subordinate commands
5.1.1.2 Coordinate with J-3 on operation requirements
5.1.1.3 Determine requirements for communication facilities/systems
5.1.1.4 Coordinate with supporting communication element (e.g., JCSE) on supportability of initial plans
5.1.1.5 Coordinate use of satellite channels
5.1.1.6 Coordinate with Joint Task Force on communications to higher/adjacent HQ
5.1.1.7 Coordinate with component commands on communication requirements
5.1.1.8 Plan for allocation of frequencies
5.1.1.9 Evaluate impact of terrain and weather on communications
5.1.2 Establish procedures for communication control
5.1.2.1 Establish communication restoration priorities for system/circuits
5.1.2.2 Establish requirements for communications control, system control, and technical control
5.1.2.3 Establish control relationships & Review COMSEC plans
5.1.3 Plan systems interfacing
5.1.3.1 Determine interface points
5.1.3.2 Identify equipment interoperability requirements
5.1.3.3 Determine levels of interfacing
5.1.3.4 Identify relay station requirements
5.1.4 Plan policies
5.1.5 Plan future communications

5.2 Operations

5.2.1 Establish communication systems
5.2.1.1 Coordinate installation, operation, integration, and displacement of telecommunications and C2 systems
5.2.1.2 Advise on the location, echelon levels, and movement of the command post
5.2.1.3 Supervise cryptologic activities
5.2.1.4 Monitor COMSEC
5.2.1.5 Supervise integration of intelligence systems into C3 system
5.2.1.6 Supervise operation of command post communication systems radio, teletype, telephone and switching systems
5.2.1.7 Ensure system continuity and engineering
5.2.2 Perform daily communication requirements

5.2.2.1 Coordinate with subordinate commands on personnel and equipment
5.2.2.2 Coordinate integration of new equipment
5.2.2.3 Manage and supervise telecommunications
5.2.2.4 Supervise restoration of system
5.2.2.5 Supervise overall system operation
5.2.3 Perform communication maintenance management
5.2.3.1 Monitor readiness status
5.2.3.2 Provide assistance and support for communications electronics components
5.2.4 Perform frequency management
5.2.4.1 Coordinate requirements
5.2.4.2 Develop contingency plans for combat operations [Ref. 83:p. 42]

Functional decomposition reveals many new requirements and component interrelationships that are essential for the mobile command post to satisfy its mission needs, performance capabilities and communication requirements. By exploring the many functions and sub-functions system engineers can predict a system's potential. If there are no systems available which can be used to satisfy a sub-function requirement, system engineers will know immediately if one should be developed, or if improvements can be made to exisiting equipment.

F. DEFINITION OF ALTERNATIVE ARCHITECTURES

The components and functions of a mobile command post, as detailed in the functional decomposition analysis, are numerous and varied. Its overall function is to serve as a "war-room" where battle staff (i.e., the key players in the decision making process) can meet. The command post must provide a centralized and secure location where planning can take place.

Commanders must have the ability to make rapid decisions using streamline operating procedures supported by decision aids and near real time display devises.

Sensor netting, information fusion, improved data storage and retrieval, and data distribution are some of the technical enhancements that may be considered.

There are three different types of suitable mobile command post configurations which can be developed for CINCCENT and his staff. The platforms to be considered are: aircraft, ships and vehicles.

1. Aircraft

Aircraft are excellent platforms for deploying C3 components. They are capable of carrying an abundant assortment of electroonic sensors and communications equipment. AWACS and E-2C Hawkeye aircraft are two examples of airborne platforms which have been operational for over a decade. These aircraft are highly mobile units which can operate up to hundreds of miles away from any threat region. However, aircraft in general require extensive logistics and maintenance facilities in order to keep them operational. Furthermore, flight crews must be continually rotated in order to prevent fatigue, and this alone proves to be too labor and manpower intensive, especially when operating in and around unfriendly nations or when access to bases are in short supply.

2. Ships

Ships have the ability to carry a seemingly endless supply of equipment and spare parts. Rotating personnel through watch stations in order to avoid fatigue is much easier to accomplish since a ship does not have to return to base. Ships, therefore, can operate and remain on station for long periods of time without resupply. However, ships are not withoput there share of limitations. They are

restricted to their watery environment. In the Persian Gulf, for example, United States naval and merchant ships paid the price for operating within the confines of an inland sea. Tankers were repeatedly hit by drifting mines and warships such as USS Stark were hit by missiles.

3. Vehicles

Vehicles of all shapes and sizes can be designed to carry a host of electronic sensors and communication equipment. They are vary mobile and can operate for extended periods without resupply. They afford field commanders by being relatively closer to the front, but also, run the disadvantages of being spotted and destroyed. Vehicles do share the same draw backs as aircraft in that they require maintenance depots nearby. They carry a small supply of spare parts, and any repairs that must be accomplished, must be done in the field. Another limitation vehicles encounter is fuel supply. The operational fuel capacty of land vehicles is considerably less than those of aircraft or ships.

G. SYSTEM ANALYSIS AND TRADE-OFFS

Figure 12 shows the trade study conducted for the three alternate architectures proposed for CINCCENT's mobile command post. The trades associated with each concept considered are, accessibility, survivability, mobility, durability, reliability and cost. The trade weights are assigned to show relative values from one to ten with one being the best. The lower numbered values are considered optimum and their combined totals indicate the best alternative to be the ground mobile command post (GMCP).

Trade Study Weights	MOE/ MOP	ALTERNATE ARCHITECTURES			Justification
		Ship	Air	Land	
1	Access to FLOT	$\boxed{3}$ 3	$\boxed{2}$ 2	$\boxed{1}$ 1	C3 Connectivity With Host Nation
1	Surv.	$\boxed{2}$ 2	$\boxed{1}$ 1	$\boxed{3}$ 3	Concealment Hardened ECCM
2	Mobil.	$\boxed{6}$ 3	$\boxed{2}$ 1	$\boxed{4}$ 2	Transportable Packaging
3	Durab.	$\boxed{3}$ 1	$\boxed{9}$ 3	$\boxed{6}$ 2	On Station Time
3	Relia.	$\boxed{9}$ 3	$\boxed{6}$ 2	$\boxed{3}$ 1	Maintenance Redundancy
3	Cost	$\boxed{9}$ 3	$\boxed{6}$ 2	$\boxed{3}$ 1	New Construct In-place Systems
Totals		$\boxed{32}$ 15	$\boxed{28}$ 11	$\boxed{20}$ 10	Ground Mobile

A Utility Function For Each Of These Measures Of Performance And Measures Of Effectiveness is Depicted

* Maintainability Not Considered

* Flexibility Not Considered

Figure 12.

Mobile Command Post Trades Analysis

(From Ref. 77)

H. CONCEPT SELECTION

The results of the trades analysis for the mobile command post favored a land based concept over sea or air based platforms. A cost effective approach would certainly support a ground mobile command post because such systems are currently being deployed by Army units such as ADDS and FAADC. Obviously they do not carry the same equipment or perform the same mission, but they are indeed mobile in nature and have been operating quite successfully over the past several years. Airborne platforms such as AWACS or the E-2C Hawkeye and sea based platforms such as USS Blue Ridge have also been operating quite effectively in their respective mission areas. These alternative systems provide an excellent example of the typical mission requirements and functional attributes that compose their overall design. The benefits of a ground based system far outweigh airborne or shipbased platforms in that a ground based command post is transportable, easily concealed, maneuverable and mobile, and can be supported by logistic commands far more readily than aircraft or ships. Aircraft and ships require runways or ports respectively which are difficult to construct in a foreign country, especially during times of conflict.

I. CONCEPT DEFINITION

The CINCCENT ground mobile command post is comprosed of a variety of technologies and electronic components. A thorough explanation of the the mobile command post capabilities is given below.

1. System Definition

The personnel function requires connectivity with the National Command Authority (NCA), CENTCOM rear, adjacent CINCs, U&S Commands and theater commanders. Such connectivity requires satellite communications, HF long haul, point to point (microwave), telecommunications, and FAX instrumentation.

The intelligence function requires the same connectivity as mentioned above with the addition of National Security Agency (NSA) sources, HUMINT, ELINT, and SIGINT via the Intelligence Data Handling System (IDHS). HF and UHF communications would serve as a back up to satellite services. Additionally, GMCP intelligence would be gathered from the CENTCOM Contingency Intelligence Communication System. This system utilizes the Light Reaction Communication System (LRCS) a portable unit which provides timely intelligence support to forward locations situated in the AOR.

The combat operations function, with its normal connectivity between theater level commanders and the NCA will require additional capability from global positioning systems, interface with World Wide Military Command and Control System (WWMCCS), the primary command and control ADP support system, via a mobile T-Host platform. Standard HF and satellite communications will also available.

The logistics group function will depend heavily on the JCSE which is normally deployed during the en route phase of deployment. It can provide three UHF satellite terminals at the proposed GMCP site, in addition to placing terminals at component headquarters, embassies, and supporting CINCs. JCSE is capable of

providing a variety of communication services from FAX to WWMCCS interfaces.

The Communications management function will operate the Diplomatic Telecommunication Service (DTS) which enables communication and exchange of information with all foreign missions of the State Department. Oversee the management of regional telecommunications, WWMCCS, military satellite SHF communications, and coordinate with logistics on the management of JCSE.

a. Communications

Communications to support CINCCENT's mission require a high degree of flexibility to respond to the entire spectrum of military activities in the area of operation, (AOR). CENTCOM communications must possess the necessary interoperability for interfacing among fixed DCS and multiservice tactical communication systems, as well as between U.S. and host nation communication systems. This allows for greater connectivity and survivability. In addition, GMCP must be able to support the transition to wartime organizational postures for the projection of a military force from CONUS to the AOR. The ability of the C3 systems to respond rapidly to a contingency in the CENTCOM AOR reflects directly upon the command capability to field the requisite quantity of reliable, survivable and easily transportable communication equipment. The numbers of functions and subfunctions the GMCP must perform immediately suggest a need for the following capabilities:

- DCS/Europe and Pacific Gateways,
- JCSE,

- Satellite communications,
- Airborne communications platform,
- HF/UHF radio systems (satellite backup),
- Deployable Intelligence Data Handling System, and;
- Component tactical communications. [Ref. 84:p. 42]

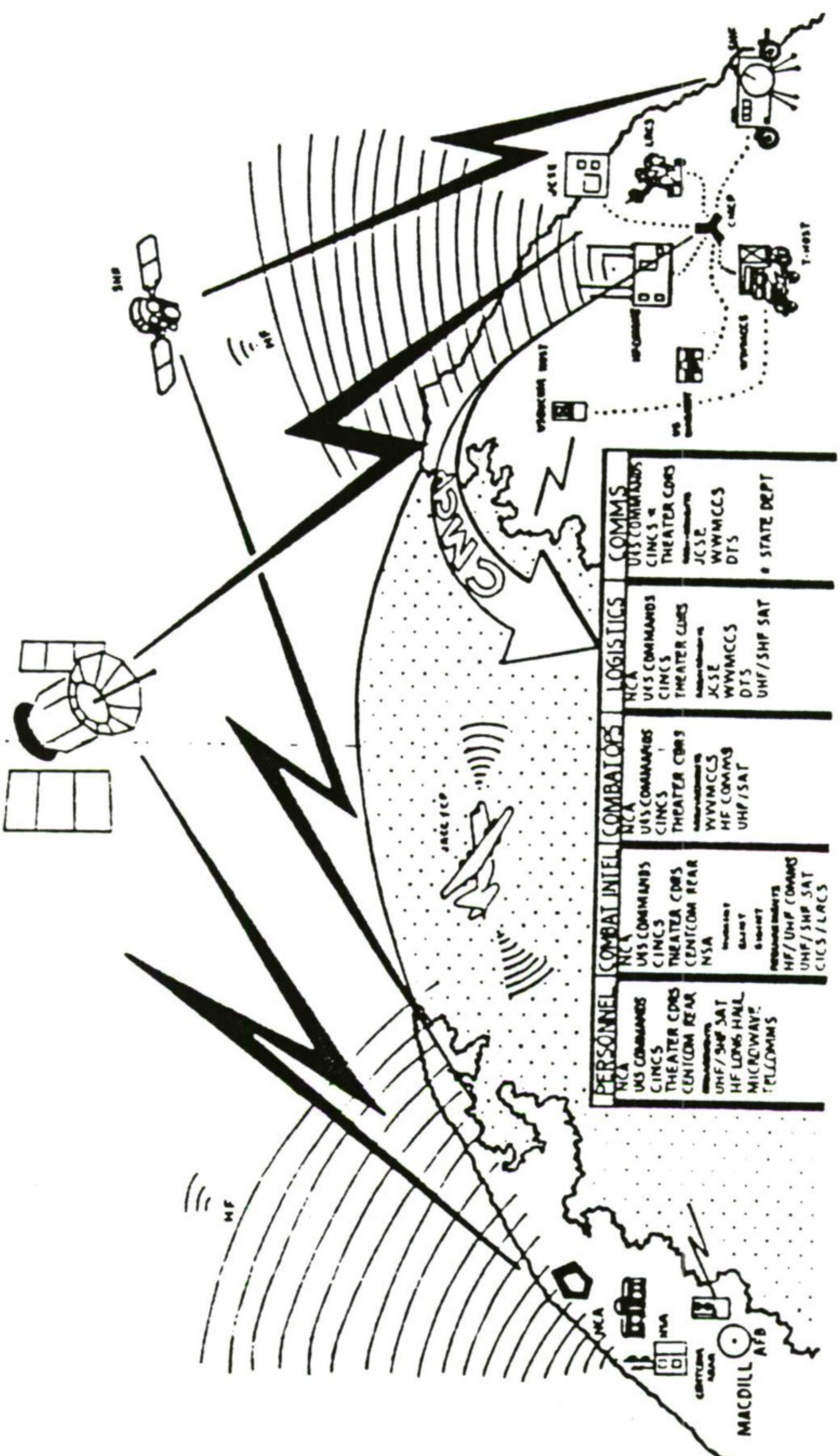
Communication gateways to the worldwide networks must also be established. Heavy reliance upon transportable UHF/SHF satellite, HF radio, JCSE and service tactical assets will be required to support AOR operations and establish links to Defense Communications Service (DCS) entry stations.

b. *Connectivity*

When positioned in the AOR the GMCP requires communications connectivity with the NCA/JCS, CENTCOM Rear, supporting U&S Commands, selected U.S. embassies, allied and/or host nation military forces, deployed U.S. forces, HQ of CENTCOM components and defense representatives, and key bases/installations in theater. Figure 13 illustrates the connectivity between the command post and various other command and national agencies.

c. *Hardware/Software Displays*

The mobile command post employs a wide variety of communications equipment, machinery and support facilities. The equipment is rugged and durable, well suited for the harsh desert environment. All equipment is modular in nature and repairs are easily accomplished even during high stress combat situations. All



ARTIST CONCEPTION BY JOHN PURNELL

Figure 13.

Mobile Command Post Connectivity

accompanying software is durable and additional back-up copies are available. Military Standard, Defense System Software Development, outlines the general approach to development of the program requirements, however the following lists a few common problems associated with software development:

- Runaway costs,
- Inability to Maintain Schedules,
- Delivery of systems which did not meet requirements, and;
- Delivered system costly to maintain.

In this system software will we developed in segments. The interfaces between segments will require special attention to prevent incompatibility, schedule slips and cost overruns.

Displays in the mobile command post must be flexible enough to meet the commander's needs and simple enough to lend themselves to accurate decision making. Miniaturization of all equipment in the command post is a realistic requirement and the display devices will be designed with decision making, human limitations, and size considerations for future component accessories, survivability, and other considerations mentioned above.

d. Weight Power Volume

Weight considerations have been tempered at the onset of this design process. Much attention has been paid to cargo restrictions for aircraft and the GMCP weight must not detract from its mobility in any situation. Unassembled, the GMCP and its support facilities are easily transportable. Once landed, they can be

driven directly off the aircraft and deployed into the AOR. Assembly of the main body can be completed in less than 30 minutes. Hook up with Mobile HF, satellite and RPV platforms can occur simultaneously and the overall system can be operational within 1 hour. Amenities such as sleeping quarters, defensive slip trenches, messing facilities can be constructed as operations dictate.

The GMCP is powered by diesel driven generators. The tractor and trailer rigs come complete with their own built-in generator. Depending on the configuration of the GMCP one generator can power all three rigs simultaneously. During battle conditions all three generators can be brought on line and paralleled. In case on is damaged, there will always be power available.

e. *Human Factors*

The GMCP was designed with its operators in mind. The trailers are compact, but give the users a feeling of security knowing there is an armor belt, and quick site evacuations are possible. This greatly improves overall concentration and produces a more responsive staff. The equipment is designed to enable users to make quick decisions and not overburden themselves with tactical information. The trailers have air conditioning systems not only for electrical equipment, but for habitability as well. The interior is spartan and every operator has a console with a comfortable chair. The command module comes equipped with a head and running water, similar to systems found in aircraft.

Support facilities, can include fuel trailers, mess trailers and sleeping facilities. Most deployed commanders prefer cots and tents, but severe sand storms can ravage these shelters.

f. Survivability Assessment

In peacetime, C3 capabilities in support of CINCCENT and the major subordinate commands are almost entirely dependent upon the DCS and commercially leased sources. At the onset of war major portions of these systems will be destroyed or electronically jammed, seriously degrading the functional capability of the C3 system.

The recommended GMCP uses three major classes of implementation action necessary to minimize disruption of communication services as forces move with the battle. These three classes of implementation action and their roles are:

- Physical and Transmission Systems Hardening - Actions that increase the likelihood of path and facility survivability during early days of conflict.
- Route and media diversity - Actions that increase the likelihood of link survivabiity throughout the conflict by allowing for extensive circuit rerouting.
- Reconstitution assets - Actions that increase the likelihood of path and facility restoral after initial damage to the network is known and which provide the flexibility to move with the forces. [Ref. 85:p. 56]

Examples of physical hardening are used to protect against pre-war events, such as: riots, terrorists activities as well as conventional warfare actions resulting from air attack, shore bombardment, and conventional ground action. The GMCP main body comprised of the trailers and command module may be fortified with a reactive armor belt. Mobile satellite, HF/UHF and remotely-piloted vehicles (RPV) platforms located away from the main body utilize sandbags and camouflage netting. All poles, waveguides and dishes are strengthened to withstand

concussion or glancing damage from artillery rounds. If set-up time permits, wired connecting reconstitution assets may be bunkered and protected with sand bags.

Transmission systems, such as: HF, satellite microwave and T-Host are hardened to protect against the effects of high altitude electromagnetic pulse and electromagnetic warfare.

Route and media diversity provide protection against wartime disruptions by reducing the concentration of circuits and providing for richer circuit rerouting possibilities. All mobile communication support systems are located away from the main body for just this reason. In the unlikely event the main body was to suffer a direct hit, the support systems offer an alternative means for communication.

Mobile reconstitution assets are specified for facilities with high likelihoods of physical destruction or overrun. They will be stored in theater prior to the start of hostilities. They will then be lifted by the most rapid means available to replaced damaged or destroyed communications equipment, or to reconstitute communications to forces that have move once hostilities have started. All mobile support communications platforms have reconstitution capability, but the best system would be the JCSE which would remain in theater for just such emergency.

J. CONCEPT OF OPERATION

Figure 14 is an illustration of the CINCCENT ground mobile command post. This system is comprised of three all terrain, diesel powered, tractor trailer rigs. When butted with the command module it forms a self-contained command post complete with air conditioning, potable water and electric generators. The internal

layout of system components and work stations are essentially the same for every trailer, and equipment weight is evenly arranged on both sides of the trailer to provide a balanced load. The GMCP furnishes the commander with the facilities he requires in order to properly control the operations of his forces. It is designed and arranged to enhance efficiency in intra staff coordination, minimize internal message traffic, and to maintain security.

The specific internal and external configurations of the GMCP is influenced by many factors, such as: functional requirements, theater terrain features, weather and personnel support. The tractor and trailer units are designed with a low silhouette for easier concealment below ridges or shrubbery. All edges are faceted to deflect radar reflections and minimize the chances of detection from enemy radar sites, a concept borrowed from stealth technology. It may incorporate the latest technology in reactive armor plating therefore diminishing the hazards of casualties from chance artillery or mortar fire. Vital components such as auwillary power sources, emergency transmitters, and receivers will be centrally located within the trailer and afforded extra protection by adjacent, less vital equipment modules. The GMCP will be located far enough forward to permit the commander positive control of his forces, but not so far forward as to draw fire from enemy positions. GMCP support facilities such as mobile satellite posts, mobile HF/UHF and RPV launch and recovery platforms will be operated in conjunction with the GMCP main body, but dispersed to provide greater survivability and measures of control.

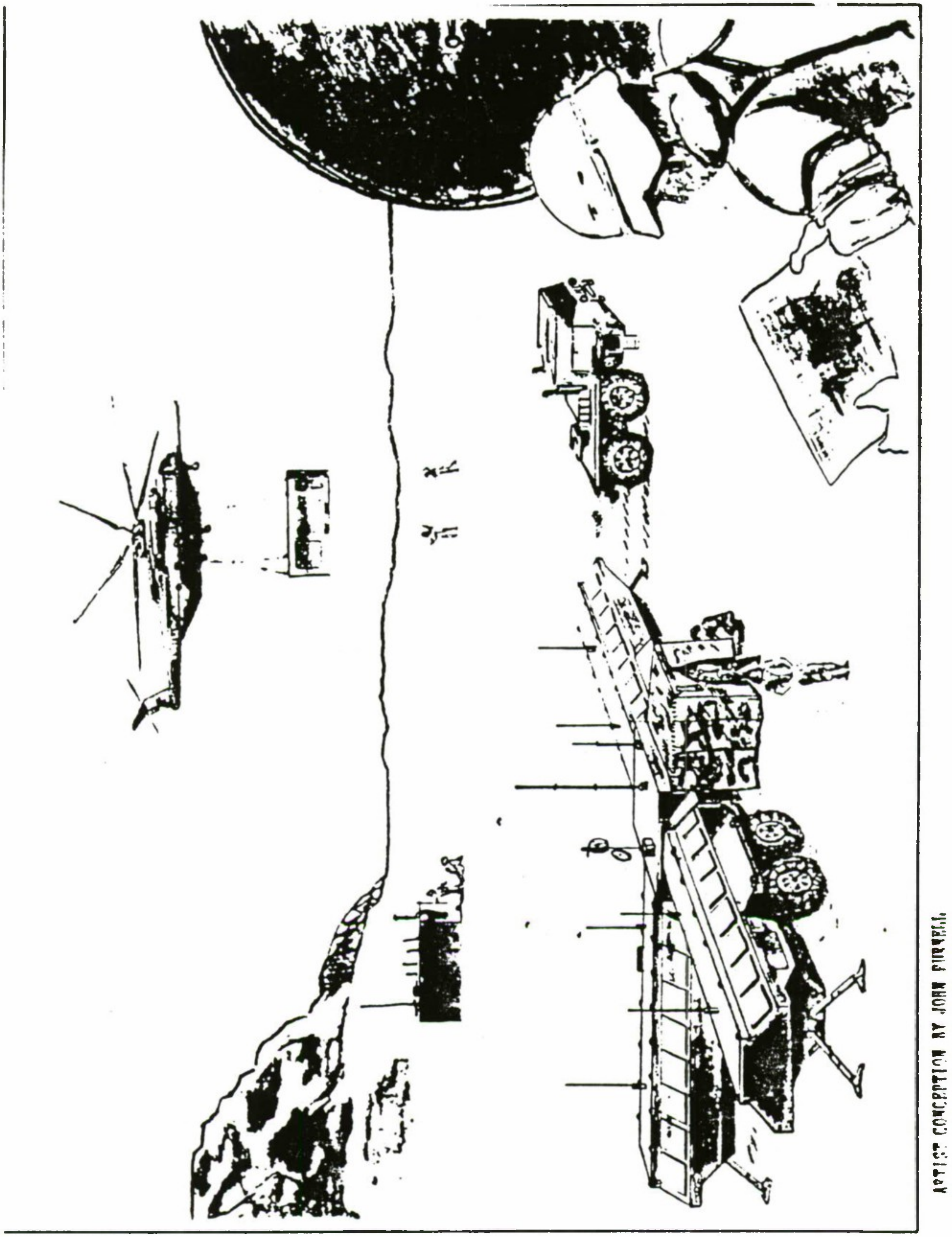


Figure 14.

Artist's Conception of the CINCCENT Mobile Command Post

K. SUMMARY

The goal of this case study was to present the procedures for developing an optimal ground mobile command post configuration for CINCCENT. The ground mobile command post example followed the system engineering stages outlined in Chapter III, transitioning from mission need all the way up to concept of operations.

The ground mobile command post incorporates a wide variety of communications, sensing and processing systems all of which contribute to the needs of the CINCCENT. The ground mobile command post has tremendous connectivity and communication abilities which allow near real-time information to be exchanged between subordinate commands and higher authority.

V. SUMMARY

This thesis has sought to present a basic introduction to the C3 system engineering process and provide an overview of the various design and creative methods which share in the development of wise system engineering practices.

Clearly, C3 systems engineering requires a thorough understanding of the system engineering process, knowledge of current C3 systems technology and a willingness to be bold and utilize our inherent knack for creative thinking. This is true whether one is considering the C3 needs of platoon level command or the needs of a higher authority such as the Joint Chiefs of Staff or the National Command Authority.

The challenges that await the C3 system engineer will be in such fields as electronics, superconductivity, miniaturization, automation and electronics. The demands to incorporate these technologies into viable systems will be greater than ever, but the C3 system engineer must be ready to meet these challenges. His greatest power will be the knowledge, that in spite of the significance of these new technologies, they can be implemented quite easily with a combination of design skills and processes that date back centuries. These processes have been refined to accommodate the ever increasing pace of technological innovations. They allow for an exchange of ideas between the members of scientific communities who strive to

incorporate the needs of the user into the development of functional and well-defined systems.

COMMANDER IN CHIEF
CENTRAL COMMAND
MOBILE COMMAND POST

A SPECIFICATION

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FIGURES

Section 1

SCOPE

1.1 PURPOSE

This specification sets forth the performance, design development, construction, and test requirements of the CINC CENTCOM Mobile Command Post hereinafter referred to as the MCP.

1.2 CLASSIFICATIONS - unclassified

Section 2

APPLICABLE DOCUMENTS

2.1 <u>GOVERNMENT DOCUMENTS</u> - TBS
- SPECIFICATIONS:
  - Federal
  - Military
  - Program Specifications
  - Other Government Activity Specifications
- STANDARDS:
  - Federal
  - Military
  - Program Specifications
  - Other Government Activity Specifications
- DRAWINGS:
- OTHER PUBLICATIONS:
  - Manuals
  - Regulations
  - Handbooks Bulletins

2.2 <u>NON-GOVERNMENT DOCUMENTS</u> - TBS
- SPECIFICATIONS:
  - Federal
  - Military
  - Program Specifications
  - Other Government Activity Specifications
- STANDARDS:
  - Federal
  - Military
  - Program Specifications
  - Other Government Activity Specifications
- DRAWINGS:
- OTHER PUBLICATIONS:

Section 3

REQUIREMENTS

3.1 SYSTEM DEFINITION

The MCP system is a critical element of the CINC CENTCOM operational command and control during conflict in the CINC's immediate area of responsibility (AOR). The major functional areas within the system include personnel planning and operations, combat intelligence planning and operations, combat operations, logistic support functions, and communications management functions

3.1.1 General Description.

3.1.2 Missions. The MCP will serve as an in-theater CENTCOM headquarters and must support all command and control functions in a hostile environment, short of general war when the MCP vulnerability is greatly increased. (refer to technical report, section IV. Mission Requirements)

3.1.3 Threat. The MCP will be subject to a variety of external threats including ground assault, air attacks, NBC warfare and ground-to-ground missiles. (refer to technical report, section V. Threat Specification)

3.1.4 System Diagrams. (included in the appendix to this specification.)

- functional flow chart
- hierarchial chart
- from/to chart
- N2 chart

3.1.5 Interface definition. The MCP must maintain organizational and communications (voice, data, secure voice and data, digital fax, and digital imaging) connectivity by interfacing to:

- CINC CENTCOM (or appropriate higher headquarters)
- National Command Authority (NCA)
- the American Embassies (AMEMB) through the Diplomatic Telecommunications Service (DTS),
- various intelligence sources through the Quick Reaction Intelligence Communications Systems,
- other CINCs, the next echelon forces and allies through the Joint Communications Support Element (JCSE) joint task force packages and DCS entry points.
- mobile ground forces through the DSCS SATCOM system
- WWMCCS

3.1.6 <u>Operational and Organizational Concept</u>. The MCP must support the integration of all functional areas in order to accomplish the mission(s). To be able to maintain operations the following critical information is necessary: personnel status; enemy activity, capabilities, estimated intentions, personnel/equipment losses, DOB, and also weather forecast; ground, air and sea operations, fire support, CBR warfare, future plans; logistics - supply, ground, aircraft, engineering, transportation, medical, sealift status; and communications of the service components, path utility, current status, circuit status reports, and WWMCCS connectivity.

The MCP organization and relationship to out of theater command and control is illustrated below.

```
                              ____________
                             |            |
                             |  NCA/JCS   |
                             |____________|
                                   |
                          USCINCCENT-----other CINCs
                                   |          AMEMBs
                                   |          Allies
                                   |------|
                                   |      |
                                   |     COMUSMARCENT
                                   |     COMUSSOCCENT
                                   |     COMUSCENTAF
                                   |     COMUSNAVCENT
                                   |     COMUSMARCENT
   aides/personal staff------------|
                                   |
                        DEPUTY COMMANDER-----aides/pers staff
                                   |
         assistant COMMANDER-------|
                                   |-----CHIEF OF STAFF
       subordinate COMMANDER-------|           |
                                      Deputy chief of staff
                                               |
                                  Special Staff (battle staff)
                                    |
                                    |- Personnel
                                    |
                                    |- Combat Intelligence
                                    |
                                    |- Combat Operations
                                    |
                                    |- Logistics
                                    |
                                    |- Communications Management
```

3.2 CHARACTERISTICS. (refer to technical report, section XI. Design Parameters)

3.2.1 Performance Characteristics. The MCP shall meet the following minimal system characteristics.

3.2.2 Physical Characteristics

3.2.2.1 Durability. The MCP shall be designed to operate under extreme environmental conditions. The system must be adverse to drastic temperature swings and in particular to excessive heat. The entire system must be resistant to dust and sand.

3.2.2.2 Survivability. Electromagnetic Pulse Hardening (EMP) is required. There are two aspects to this issue. One is the survivability of the mobile command post itself, the other is the survivability of the electronic communications. (refer to the technical report, section XII. Survivability Assessment)

3.2.2.3 Size. No more than ten trailer-sized mobile units is specified. This limitation is due to transportability requirements.

3.2.3 Reliability. The reliability allocations shall assure that the overall mission reliability requirements are met under the most severe extremes of storage, transportation, testing and operations. To the extent practical, the MCP design shall be such that a failure in one component shall not propagate to other devices or components. The MTBF must be no less than 5000 hours.

3.2.4 Maintainability. The MTTR for the MCP must be less than 1 hour for limited maintenance field repairs. Spare parts are required to ensure minimum system down time. Depot repair is available but not feasible for a short conflict scenario. Everything possible should be done and precautions taken to keep the system up and operational on a constant basis.

3.2.5 Availability. The MCP shall be readily available and immediately deployable. Backup subsystems may be required in order to meet the reliability and maintainability requirements.

3.2.6 Transportability. The entire MCP system must be able to fit onto a 5 ton truck and be transported by containerized cargo ship or cargo air assets. This limitation will allow for the rapid deployment of the command facility.

3.3 DESIGN AND CONSTRUCTION. (refer to technical report, section XI. Design Parameters.)

3.3.1 Materials, processes, parts. The materials shall be corrosion resistant or suitably treated to resist corrosion when subjected to the middle eastern, dry-arid climate. The finish shall be such to prevent any type of corrosion which would interfere with meeting the specified performance of the device or its associated parts. Parts and materials shall be selected that have demonstrated their suitability for the intended application; taking into consideration the environment, combustibility, and part compatibility.

3.3.2 Safety. The MCP design shall be such that a safety hazard to personnel and surrounding equipment shall not be created during installation, maintenance, ground test, transportation, and operational use. Safety procedures shall be documented and implemented to assure maximum freedom from accidents attributable to facilities, equipment, and personnel.

3.3.3 Human performance/engineering. The MCP system is required to obtain effective, compatible, and safe man-equipment interactions. Provisions shall be made to prevent incorrect assembly which may impair the intended functions.

3.3.4 MIL-STD-483 Computer Programming for standards on program structure, top down design, structured coding, programming languages, etc. - TBS

3.4 DOCUMENTATION STANDARDS

Only documentation listed in the Contract Data Requirements List (CDRL) is formally delivered for review or approval. However, during the course of the system acquisition, results of trade studies, analysis, and development efforts shall be internally documented to support critical design decisions and technical reviews. The final system documentation should also be adequate to allow the rapid incorporation of changes and modifications by the contractor should they be necessary or desired. The documented operational procedures should include contingency procedures to minimize to a practical extent the impact of possible anomalies.

3.5 LOGISTICS

This element must be a planned and coordinated effort between the MCP field unit, each component service support groups in the CINC's course of action, and host nations. Logistics for the MCP must take into consideration available reserve materials in order to support war reserve and sustainability requirements. All functional area aspects must be examined separately and collectively.

3.5.1 Maintenance. Limited field maintenance is required. Redundancy of system parts may be required to meet reliability requirements.

3.5.2 Supply. The MCP must be able to survive, self-contained for a period of 180 days without resupply.

3.5.3 Facilities and Equipment. The MCP must serve the command and control need of the commander and his mission. The system must also support the personnel and equipment required under this CENTCOM mission requirements statement.

3.6 PERSONNEL AND TRAINING. Approximately 100 people, made up of a variety of the four services, will be necessary to support the MCP mission. Facility equipment training of personnel and scenario exercise will be necessary as mission preparatory training.

3.7 FUNCTIONAL AREA CHARACTERISTICS - (refer to technical report, section VIII. Functional Decomposition.) The functional areas are broken up as follows:

a) Personnel,
b) Combat Intelligence,
c) Combat Operations,
d) Logistics, and
e) Communications Management.

Section 4

QUALITY ASSURANCE

4.1 GENERAL

4.1.1 Test Responsibility. Unless otherwise specified in the contract or purchase order, the contractor is responsible for the performance of all inspection and test requirements specified herein. Except as otherwise specified in the contract or order, the supplier may use his own or any other facilities suitable for the performance of the inspection and test requirements specified herein unless disapproved by the government. The government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure that supplies and services conform to prescribed requirements.

4.1.2 Classification of Inspections and Tests. These tests are set aside in the Quality Conformance Inspections section, 4.2.1 through 4.2.7. These categories are intended to encompass all tests and inspections required during the system acquisition.

4.2 QUALITY CONFORMANCE INSPECTIONS

4.2.1 Parts, materials, and process controls. Parts, materials, and process controls are to be applied during production of all items to ensure that a reliable system is fabricated. All parts and materials shall be adequately controlled and inspected prior to assembly. During fabrication of the MCP and subsystems, the tools and processes, as well as parts and materials, shall be adequately controlled and inspected to assure compliance with the approved manufacturing processes and controls.

4.2.2 Engineering Design Verification.

4.2.3 Qualification Tests. Qualification tests shall be performed to demonstrate, to the extent it is practicable, that devices that are manufactured in accordance with the approved processes and controls meet the specified design requirements. Qualification is required for the entire MCP and subsystems. All qualification tests shall be conducted with hardware of the final design that have passed the in-process production screens.

4.2.4 Acceptance tests. Acceptance tests shall be performed as the basis for acceptance of items manufactured Acceptance tests, including lot certification testing, is that testing performed to demonstrate confidence that production devices that have passed the in-process production screening also meet the other

requirements specified.

4.2.5 Service life verification. Service life verification tests are defined as those tests conducted on limited life devices to demonstrate that production devices will perform satisfactorily during their specified service life. Explosive ordnance devices and other components whose performance may degrade with time shall have life extensions based upon passing either an aging surveillance test or an accelerated aging test.

4.2.6 Pre-Deployment tests. The contractor shall perform system tests prior initial operational capability. These tests should prove out the intended quality and reliability of the equipment and system design to avoid major operational difficulties.

4.2.7 Operational tests. Operational tests must emulate a near-real conflict and environmental conditions so that the MCP can be proven as meeting the original mission requirements.

Section 5

PREPARATION FOR DELIVERY - TBS

Section 6

NOTES - TBS

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